Control ENGINEERING

INSTRUMENTATION AND AUTOMATIC CONTROL SYSTEMS

A McGRAW-HILL PUBLICATION

PRICE 50 CENTS

JANUARY 1956

AN EDITORIAL PREVIEW FOR '56

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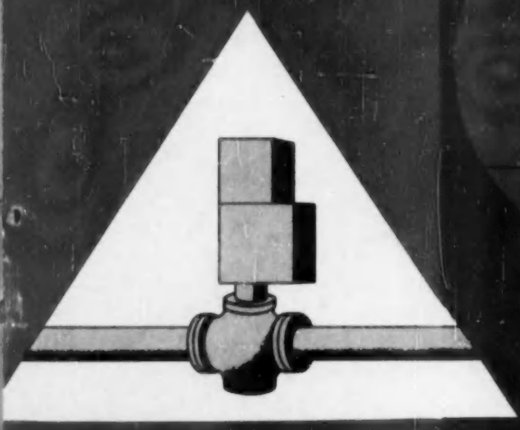

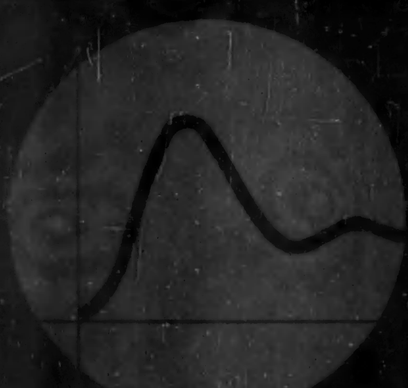

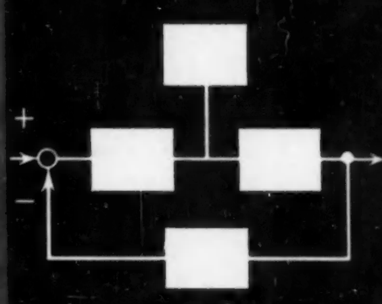

where can you match the precision performance of this

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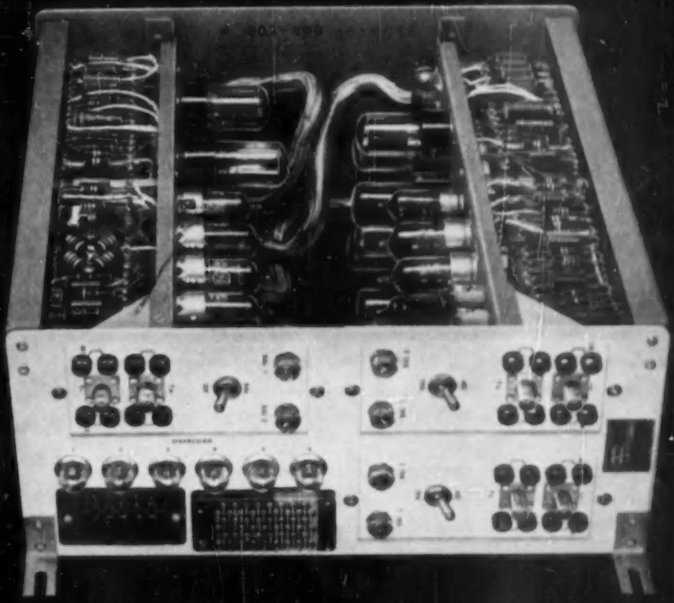

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• • •

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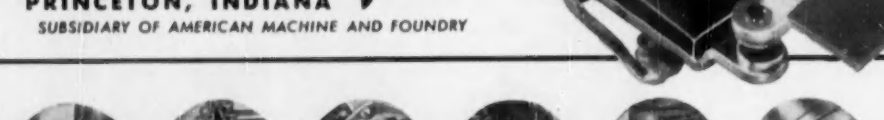


Clip-on solderless — Pierced solder lug — Tube type octal plug — AN type connector — Standard screw terminals — Up to 14 pin plug-in

Control ENGINEERING

JANUARY 1956

INSTRUMENTATION AND AUTOMATIC CONTROL SYSTEMS

PRINT ORDER THIS ISSUE 28,655

SHOPTALK

MENU PLANNING FOR '56

Trudging cross-town on jangling 42nd street one brisk day we got the idea—by most devious means, you'll see—for this month's cover. Somewhere between 7th and 8th avenues, eyes downcast to avoid the lurid distractions, we niffed the air and smelled roast beef. With this our head jerked up and there we saw . . . THE AUTOMAT. Do control engineers like to eat at the Automat, we mused. Does the idea of push-button selecting a meal (system) from food components satisfy technical as well as gastronomic inclinations? Right then and there we decided to investigate the approach on this month's cover.

Our idea was to make our cover a literary Automat: to display our editorial menu for 1956 in nice sanitary boxes that could be eyed by the hungry subscriber and planned into future hours of epicurean reading. Our master Chef—Art Director Jack Gordon—was all poised with skillet and easel to serve up the viands. But what? Where? And how? We were faced with the formidable problem of classifying control information into courses and dishes and putting it on shelves. Take the individual servings. Would, for example, a steel mill man consider a computer a component or a system? (Is the tomato a vegetable or a fruit?) And how create the courses? Are process control and production control as clearly different as fish and meat? Also, could one make a genus of digital techniques—much like one would group beer and milk into beverages? We pondered . . . and Jack's skillet grew cold, his easel drooped.

THREE MAIN COURSES, plus aperitifs

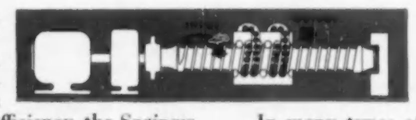
Finally, the menu was planned. As the cover shows, we gave Jack three main counters to vend our dishes on—assuming that any hungry control engineer will always require a full meal of components, design tools, and systems stuff. Then we offered the discriminating reader a choice. Would he prefer to sample available components? Or would he prefer to mix his own salad? Would he like a graph or an equation for his main course? Does he enjoy a dessert that is fluid—or discrete? Luckily, the space on a cover is limited. Hence we could only present a brief sample of our editorial fare for 1956. We could not list the many carefully selected aperitifs (PULSE, PERSONALITIES, NEWS, etc.) that will garnish each month's menu. Nor myriad other dishes that are planned (but hard to classify). But we hope that what is listed will whet the appetite and result in hearty reading in the year ahead.

Solve your critical positioning problems with the

SAGINAW ball/bearing SCREW!

Typical miniature *Saginaw b/b Screw* specially engineered for electronics application. Length: 3 inches; weight: 2½ ounces. Other units have been built as short as 1½ inches.

Compact, "flyweight" design . . . hairbreadth precision . . . zero torque . . . "fleapower" operation . . . unprecedented efficiency and dependability make these units ideal for positioning controls in transducers and similar applications



Operating on a remarkably small amount of power because of its 90% to 95% efficiency, the *Saginaw ball/bearing Screw* can translate rotary to linear motion (or vice-versa) far *more efficiently than any other type of mechanism known.* Instead of *sliding,* mating surfaces *glide* on steel balls recirculating in closed-circuit raceways.

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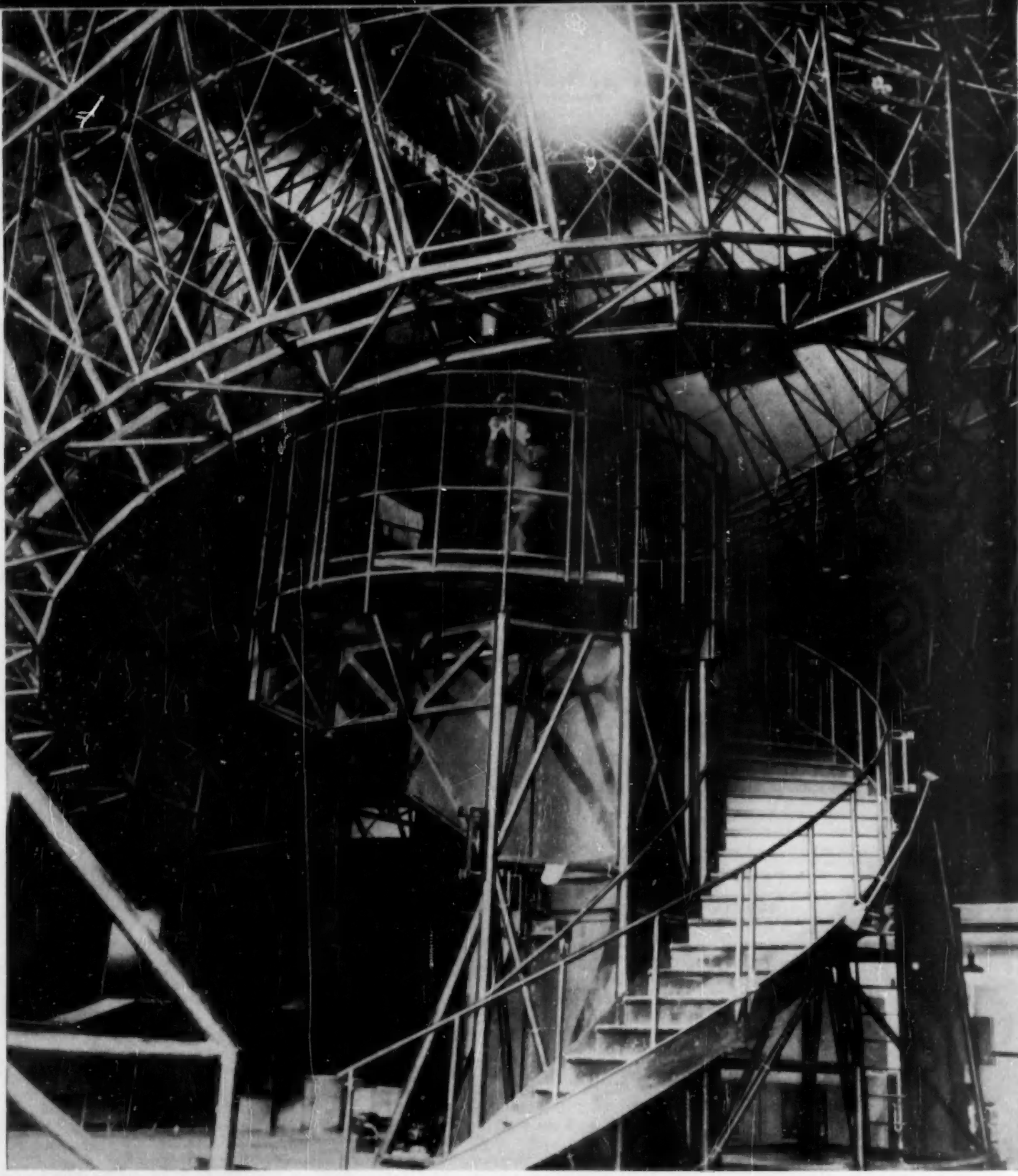

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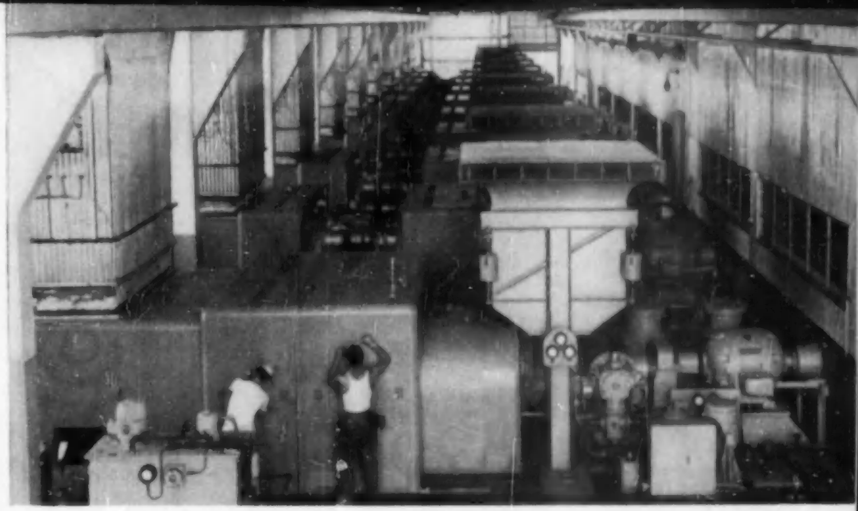
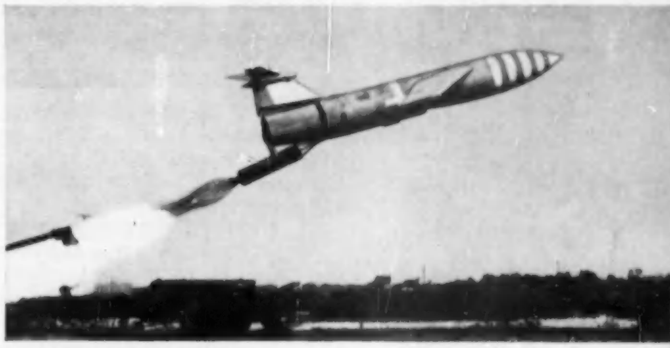


PROCESS CONTROL—Askania controls regulate speed of the ten turbines which develop compression to maintain gas suction pressure in Creole Petroleum Corporation's giant, pile-supported oil drilling operation on Lake Maracaibo, Venezuela.

SUBMARINE OPERATION — Controls developed and produced by Askania Regulator Company are utilized to govern operation of U. S. Navy's modern Guppy type submarines.



MISSILE GUIDANCE —One of the many guided missiles equipped with Kearfott basic gyro reference systems, the B-61 Matador—U. S. Air Force's first successful ground-to-ground tactical weapon.

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ELECTRICAL EQUIPMENT and COMPONENTS	●●●	●	●			●●●	●●●	●●	●	●●	●	●●●
ELECTRONICS	●●●	●●	●●●	●●●		●●●	●	●●		●●●	●●	●●●
HYDRAULICS, LIQUIDS PROCESSING, HEAT EXCHANGE		●●			●●●					●●●		
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AUTOMATIC COMPUTERS and COMPONENTS	●●●	●	●	□●●		●●●				●●●		●●●
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themselves, as well as in systems and equipment developed and produced by other manufacturers of advanced technological equipment.

All GPE Producing Companies work in the advanced areas of highly specialized fields and are engaged in the design, development, manufacture and sale of equipment which is closely related from a technical point of view. It is all precision equipment; it derives from similar fields of technical competence; it saves labor, increases productivity or achieves results which cannot be achieved with even limited use of on-the-spot manpower. The chart here shows the specialized fields in which the key GPE Producing Companies work.

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A brochure relative to the work of the GPE Companies and GPE Coordinated Precision Technology is available. Address your request, or specific inquiries, to: General Precision Equipment Corporation — 92 Gold Street, New York 38, N. Y.

FEEDBACK

Boogered binary . . .

To the Editor—

I compliment Control Engineering and Mr. Lerner on his article on numbers system which appeared in your Nov. issue. The article did, however, overlook one numbers system which is becoming even more important.

The Gray Code (known also as cyclic binary, non-ambiguous binary, or more simply "boogered binary") is used on digital shaft coders such as the brush commutator type manufactured by Giannini, and the photoelectric type manufactured by Electronic Corp. of America and Baldwin Piano Corp.

Ralph P. Graeber
RCA Systems Engineering
Patrick Air Force Base
Florida

In his letter, Mr. Graeber continued with a description of the Gray Code. But we received another letter on this subject, from which we extract the details of this important coding procedure. Ed.

. . . and vanishing error

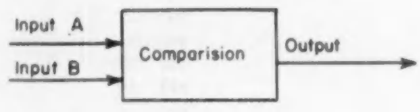
To the Editor—

In shaft-type analog to digital converters a particular binary code, called variously the Gray, reflected, or cyclical binary code, is often used. As may be seen from a comparison of the two codes (page 9), the Gray code involves a change of only one element in going from one combination to either of the adjacent combinations. But in the normal binary code there may be any number of element changes.

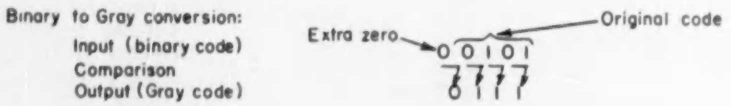
If readout is attempted during a transition between combinations in the normal code, it is possible that only a partial transition has occurred. If this is the case the output code may be far removed from either of the two code

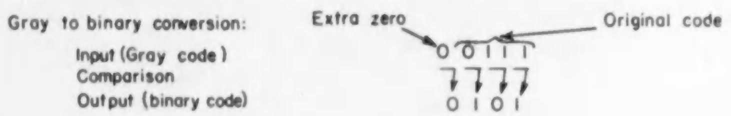
BINARY-GRAY CODE CONVERSION: Mr. Crocker says, "Compare the two inputs . . .

Input		Output
A	B	
0	0	0
1	1	0
0	1	1
1	0	1



. . . but be sure to prefix a zero."





JANUARY 1956 Control Engineering VOL. 3 NO. 1

Published monthly by the McGraw-Hill Publishing Co., Inc., Executive, Editorial, Advertising and Subscription Offices: **McGraw-Hill Building, 330 West 42nd Street, N. Y. 36, N. Y.** Publication Office, 99-129 North Broadway, Albany 1, N. Y.; entered as second class matter at the Post Office at Albany, N. Y. Donald C. McGraw, president; Paul Montgomery, executive vice-president; Joseph A. Gerardi, vice-president and treasurer; John J. Cooke, secretary; Nelson Bond, executive vice-president, Publication Division. Ralph B. Smith, vice-president and editorial director; J. E. Blackburn, Jr., vice-president and circulation director; Joseph H. Allen, advertising director. **FOR SUBSCRIPTIONS,** write to: Control Engineering-Subscription Service, 330 West 42nd Street, New York 36, N. Y. Orders must indicate company and position. Allow one month for change of address. Single copies 50¢. United States and possessions: $3 for one year, $4 for two years, $5 for three years. Canada: $4 for one year, $6 for two years, $8 for three years. Latin America: $10 for one year, $16 for two years, $20 for three years. Other countries: $15 for one year, $25 for two years, $30 for three years. Printed in U.S.A.

combinations involved. Since only one element changes during a transition in the Gray code, the problem of partial transition vanishes with its use.

Decimal value	Normal binary	Gray binary
Weighting →	8 4 2 1	15 7 3 1
0	0 0 0 0	0 0 0 0
1	0 0 0 1	0 0 0 1
2	0 0 1 0	0 0 1 1
3	0 0 1 1	0 0 1 0
4	0 1 0 0	0 1 1 0
5	0 1 0 1	0 1 1 1
6	0 1 1 0	0 1 0 1
7	0 1 1 1	0 1 0 0
8	1 0 0 0	1 1 0 0
9	1 0 0 1	1 1 0 1
10	1 0 1 0	1 1 1 1
11	1 0 1 1	1 1 1 0
12	1 1 0 0	1 0 1 0
13	1 1 0 1	1 0 1 1
14	1 1 1 0	1 0 0 1
15	1 1 1 1	1 0 0 0

The normal code may be used "as is" in a digital computer, or it may be easily converted to decimal form, either with a matrix or by weighting as shown.

However, the Gray code is not as simple in this respect. Although it may be converted to decimal form with a matrix, it can be converted by weighting only if alternate signs are attached to the weighting.

The most useful procedure seems to be conversion of the Gray code to the normal binary code. This conversion involves a series of comparisons using rules in cuts on page 8.

Prefix a zero to the original number which is to be converted, then proceed. The line extends underneath the two numbers to be compared and the arrow points to the result of the comparison.

These processes may be carried out automatically with "logic" circuits if conversion is necessary as part of a system.

David C. Crocker
Instrumentation Lab.
Massachusetts Inst. of Tech.
Cambridge, Mass.

Another way to skin a cat

To the Editor—

Mr. Victor D. Corey's article *Calibrate Angular Accelerometers Without Precise Accelerations*, in the August 1955 issue of Control Engineering is of direct interest and value to me and to the people with whom I work. Mr. Corey proposed to calibrate angular accelerometers without precise acceleration by milling the output of a calibrated linear accelerometer with the angular accelerometer being tested.

It has occurred to me that Mr. Corey's method might also be valu-

able for testing rate gyroscopes, merely by rotating the axis of the calibrated linear accelerometer 90 deg so that it is parallel to radius r of Mr. Corey's Figure 1. The linear accelerometer for testing rate gyros under these conditions must have a functional, rather than a linear, output, but the nulling error would be proportional to the square root of any inherent deficiency in the standard linear accelerometer.

Here's a useful kink; any others? Ed.

Dynamic analysis proves a point

To the Editor—

The other day we ran into an interesting comparison between alternate temperature control systems for a distillation column. The alternatives were: (1) the temperature controller resetting a flow controller on the distillation column's reboiler steam supply, and (2) the temperature controller resetting a pressure controller on the steam chest of the reboiler. Briefly, these are the results:

(a) The flow controller cannot hold heat input constant during steam supply pressure changes.

(b) The reboiler presents a time constant of such length that it is the major effect in determining the low ultimate frequency of the temperature control system. The pressure control system has this time constant within its loop, essentially eliminating (by its high gain) the large time constant from consideration. Thus, the ultimate frequency for the overall temperature control system is determined by the next smaller time constant, shifting the operating frequency to a higher range.

We conclude that we should always use the second alternative.

It's always a pleasant experience for these little points to fall into such a sensible pattern that the "best" system can be recommended. I thought that you, too, would be interested in these results even though they are brief.

Bruce E. Powell
El Sobrante, Cal.

Our readers are always interested in specific examples of theory at work. Tell us more. Ed.

A group for control education?

To the Editor—

For the past several years, I have lived in hope that some day the ISA

would promote an informal organization of process control engineers within the Society. I thought, perhaps, you might know whether or not such a move is planned and if so, you could give me a list of interested persons.

From an educational standpoint, there has never been a time when an organized effort of process control engineers was needed so badly. This is due to the fact that there is no formal education for process control engineering, which means that a person must secure his formal education in some other phase of engineering and then spend several years serving his "internship" in some well organized industrial process control engineering group, learning to select and apply the proper instruments to control complex processes in our modern industrial processing plants. This situation accounts for the lack of interest in process control engineering by those who have the necessary educational background.

The misapplication of process control instruments being made by improperly trained process control engineers costs industry hundreds of thousands of dollars each year. This conclusion has been forced upon me by many years of association with the problems of process control. In recent years, I have been permitted to assist in solving many process control problems in our own organization and in some of our government's large installations. It is hard to believe, but almost without exception the trouble was caused by the misapplication of process control equipment. It seems to me that the only solution to the problem is for the process control engineers to organize in a group and devote their efforts toward a planned program for recruiting and educating interested persons in control engineering.

G. C. Carroll
Principal Instrument Engineer
Engineering Services Section
Olin Mathieson Chemical Corp.
Baltimore 3, Md.

We suggest that all of our readers who are interested in group activities for process control engineers contact members of ISA's Society Structures and Planning Committee. The committee is currently studying the formation of divisions by job-function and by industry within ISA. Let your interests be known to the committee's chairman, Phil Sprague, Jr., President, Hays Corp., P. O. Box 299, Michigan

City, Indiana. He will be glad to have your comments and to pass them on to the appropriate subcommittee. Ed.

Leads with chin

To the Editor—

Could you help a faithful reader with some information?

I am looking for a university at which to do post-graduate work on some engineering aspect of digital computers and would thank you for the names of six or eight places in the states that have a reputation in this field.

K. Maling
Toronto 12, Ont.

We're always glad to help one of our readers, faithful or fickle, especially if the information we gather for him is useful to our other readers. We sent Mr. Maling a three-page annotated list of approximately one hundred universities that have computer facilities. The list was prepared by Professor Harry H. Goode, National Chairman, IRE Professional Group on Electronics Computers Student Relations Committee, Willow Run Research Center, Engineering Research Institute, University of Michigan, Willow Run Airport, Ypsilanti, Mich. The Transactions of the IRE Professional Group on Electronic Computers featured the list in its June, '55 issue. Four of the universities listed grant degrees, eight offer assistantships, and 17 handle theses on electronic computers. These facilities present many openings for post-graduate work of the type sought by Mr. Maling and excellent opportunities for extension course training of nonresident engineers.

Our editorial contacts indicate that Mr. Maling's requirements are particularly well met by the following:

- ▶ University of Michigan (same address as Professor Goode's)
- ▶ MIT Digital Computer Lab, Cambridge 39, Mass.; contact Dr. Jay W. Forrester
- ▶ Harvard University Computer Lab, Cambridge, Mass.; contact Dr. Howard H. Aiken
- ▶ University of Pennsylvania, Moore School of Engineering, Philadelphia, Pa.; contact Dr. M. Rubinoff
- ▶ University of Illinois, Urbane, Ill.; contact Dr. James E. Robertson
- ▶ Purdue University, Lafayette, Ind.; contact Dr. A. Perlis
- ▶ University of California, Berkeley, Calif.; contact Professor P. L. Morton

Good hunting. Ed.

Here is one of a series of advertisements we are running in FORTUNE and BUSINESS WEEK to acquaint company managements with our interest and our experience in the field of automation and data-processing.

We believe we are making good progress in developing activities that should ultimately give us a strong position in the tremendously important and rapidly growing field of automation.

Positions are available for scientists and engineers in these fields of current activity:

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At Ramo-Wooldridge the difficult demands of major military systems responsibility have been met successfully by the placing of heavy dependence upon teams of unusually well-qualified, mature and experienced scientists, operational procedures experts, and engineers. These teams deal with the technical and non-technical portions of a project as inseparable and interrelated aspects of a single problem.

Similarly, work has been done in the last two years by this company on systems problems of non-military clients from such diverse fields as manufacturing, banking, transportation and public utility. The results strongly support the conclusion that many of the difficult problems in automation that face business and industry today can be economically solved by teams that include a breadth of technical and non-technical competence which permits them to conduct a highly objective, scientific analysis of a client's operations and requirements.

One important advantage to the client of such a broad and objective approach to his problems is the possibility of recommendations that realistic operational needs can be met without the necessity for investment in any additional machines or equipment. Nevertheless, the technical strength of The Ramo-Wooldridge Corporation, provided by its hundreds of scientists and engineers, is such that it can also undertake successfully the development of entirely new equipment and techniques, if required. As an example, major programs are currently under way on the development of an advanced type of digital computer and control system, and on the automation of large-scale data processing activities.

To a surprisingly great extent, military electronics experience has charted the course for non-military automation. A major objective of The Ramo-Wooldridge Corporation is to assist business and industry in moving rapidly, yet realistically and economically, to take advantage of the great benefits of the new techniques.

The Ramo-Wooldridge lecture hall during a lecture on Operations Research, as applied to the solution of management problems.

PACIFIC SEMICONDUCTORS, INC., a subsidiary devoted to the development and manufacture of advanced types of semiconductor devices such as diodes and transistors... of great importance in the future apparatus of automation.

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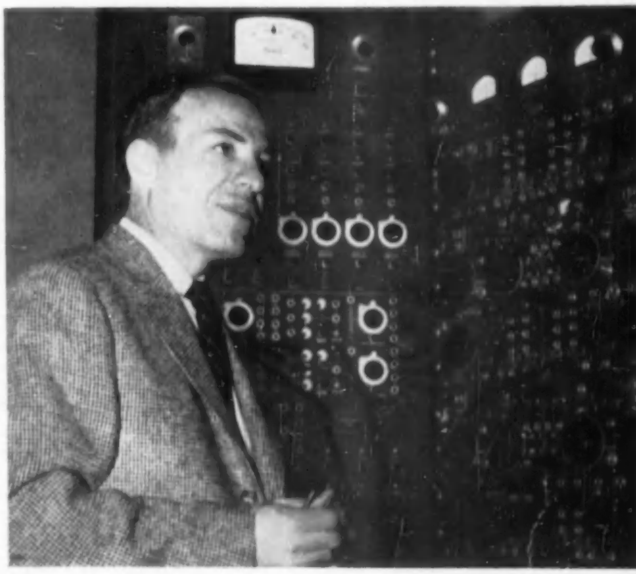
A CONTROL PERSONALITY

JOHN R. RAGAZZINI
raises systems and students

Teaching graduate courses, heading Columbia's Electrical Engineering Dept., directing an important control research project, and acting as consultant to four large firms is surely too big a load for one man. But it doesn't seem to faze Prof. John R. Ragazzini. Visitors to his simple and immaculate office find an amiable and soft-spoken fellow who looks quite a bit younger than his 43 years. "This isn't the office you'll usually find me in," he admits with a smile, "I have another one that I hide in." But it's well known that students with problems have no difficulty finding his hideaway.

Professor Ragazzini was born in Manhattan's Greenwich Village in 1904 and attended grammar school in an area not overburdened with model citizens. "I think that there are only three of us from my grammar school graduating class that managed to stay out of jail," he remarks with a grin. However, a good technical high school prepared him for CCNY, where he made Phi Beta Kappa while going for his BS. An EE degree followed in 1932.



Dr. Ragazzini takes pride in the sampled-data controller his students developed—see CtE, September 1955, p. 107.

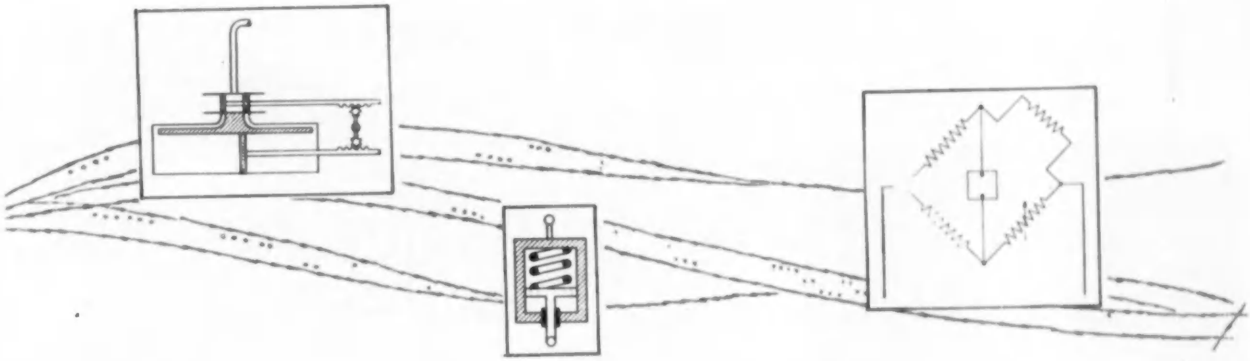
No jobs—no problem

"There was no problem getting a job those days," he says, "there just weren't any." But he was fortunate enough to become an Engineering Assistant for New York City and in 1935 a part-time instructor at CCNY while beginning graduate work at Columbia. He began a complete "re-education" (which he felt advances in electronics demanded) including enough non-technical courses to earn an MA in 1938. Soon after receiving his PhD from Columbia in 1941 (his thesis was on the rectification of noise) he became an instructor there.

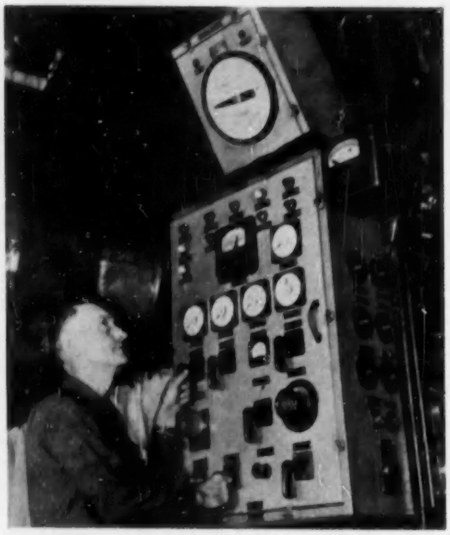
With the war Ragazzini went to MIT for a brief course in microwaves, which he then taught to military and industrial personnel at Columbia for the duration. In '44 he directed construction of an electronic analog computer to analyze equations associated with bombing and gunnery. This work led to the completion of a system, including simulated airplane controls, for analyzing aircraft and pilot performance in following moving targets. Part of this development was a simulator of a human being in a tracking situation (based on measured transfer functions). When the School of Engineering terminated military research contracts in 1945, the professor turned from his computer project to become a control consultant and do research, mainly in guided missiles.

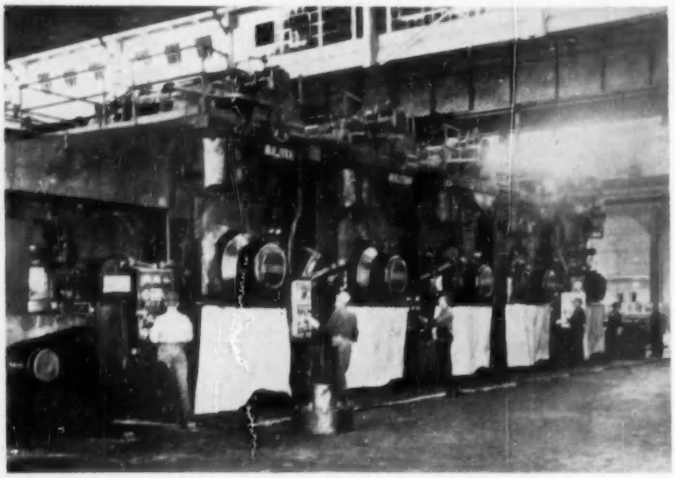
When the school reactivated research for the armed services in 1950, Professor Ragazzini started the Electronics Research Laboratories, which now handle a yearly $1 million worth of research in various phases of radar digital and analog computers and control. Interest in obtaining control data from the sweeps of radar antennas led him into pioneer studies of sampled-data control. His recent activity in this area includes considerable work in industrial processes. Not long ago he resigned as director of ERL in order to personally run one of its basic projects in sampled-data control systems. And a year ago he instituted the Control Systems Lab and took over the EE Dept., now 500 students strong.

Ragazzini, a past director of IRE and vice-chairman of AIEE's Feedback Controls Committee, commutes each summer to the Connecticut shore and to his wife, son 9, and daughter 7. Today his favorite other-than-work interests are marine sports, but some day, he says, he hopes to be occupied with a sports car.



from Brooklyn





Strip steel whipping through the five roll stands of this tandem mill at 4,000 ft per min is gaged by x-ray indicator-controllers (left) and is automatically held within 0.5 mil tolerances. But there's more to this story of how . . .

Feedback Control Tames Steel Strip Milling

PITTSBURGH, PA., Nov. 10, 1955—Sheer size and productivity of the process alone make the automatic control of a tandem cold reduction steel mill a major milestone. But General Electric and U. S. Steel in their combined effort at the latter's Irvin Works near Pittsburgh have added at least four "extras" for the feedback hall of fame:

- a system design based on a complete dynamic analysis of the process
- dual x-ray gaging both on incoming and outgoing sheet from the mill
- a combination of screwdown and speed control on the reduction rolls
- exclusive use of transistors and magnetic amplifiers in the system

According to G-E engineers, development of the system got its start in Schenectady a few years ago when they resolved to feed the basic industrial problem—how to automatically hold strip steel tolerances—into an electronic differential analyzer. As the real problem unfurled the analysis started to include not only all electrical constants, but mechanical constants such as roll pressure and interstand tension as well as the ability of the basic drive system to perform minor ironing out of incoming gage variations. With U. S. Steel cooperation, data on real time operation was brought in. Ultimately, when the system was designed it was based on an authentic dynamic analysis of the reduction process—a pioneer work in itself. The system was then built by G-E's Industry Control and X-Ray Depts.

Preventive Medicine

G-E's X-Ray Dept.—well up on medical lore—suggested preventive diagnosis as an improvement in the gaging system. For several years it had been customary to use an x-ray thickness gage between the last stand and winding reel of the mill to get an indication of finished strip thickness for manual control. Since it was generally agreed that the main reason for variation was the lack of uniformity in incoming strip, why rely on a "postmortem" measurement? The engineers suggested an additional gage in an early stage of the mill and possible control therefrom.

In the analysis it was discovered that variations in incoming strip could be substantially reduced through control of stand 1 roll opening and roll speed. After this first pass, further cold reducing renders the steel strip more brittle and susceptible to breakage, thus cuts down the possible range of control in later stands. Hence the additional gage was located between stands 1 and 2.

Measurement established, the automatic control system that evolved consisted of two portions: A coarse regulation of screwdown motors on stand 1, based on first reduction in thickness, and a vernier control of the drive motor speed on the last stand, based on outgoing strip thickness.

Error signal for the coarse regulation of stand 1 is produced by an x-ray source below the emerging strip and a detector suspended above. When the steel deviates in thickness this signal activates a transistorized discriminator which observes the direction of error and its magnitude. A polarized dc signal is then passed into an on-off time circuit containing magnetic amplifiers. On-timing is a function of the deviation signal magnitude: if steel from stand 1 is 0.5 mil off gage, the screwdown motors will run a shorter time than when the steel is off 0.7 mil.

Besides variable time operation of screwdown motors on stand 1, a check interval is introduced between timed control pulses to allow the strip to pass from rolls to gage so that the correction is "observed". Since strip speed can vary over a wide range, this off-timing interval changes inversely with operating speed of the mill.

Functions for Mill Peccadillos

Several auxiliary functions had to be integrated into the coarse control to match it to mill characteristics.

For one thing, the major part of off-gage steel supplied to such a mill is usually off-grade toward the head and tail ends of the strip. This requires a "screw-reset" function which returns the screws to a normal position at the end of a coil. A "screw departure" indicator continuously advises the operator of the deviation from normal position. Also, automatic "screw departure limit" circuits prevent the rolls from assuming positions which will overload the drive motors or cause excess slippage. When these circuits act, an alarm light tells the operator that his control is off automatic operation. Still another safety circuit—the "regulator inspector"—will make the control system inoperative if it does not reduce thickness error during a preselected time period. And, again, the operator is notified by a signal light.

The Final Reckoning

The final control of strip thickness is achieved by automatic regulation of stand 5 speed and of the strip tension between stands 4 and 5. In this last stand the mill motor gets its power from a common source which also supplies power to the other stands of the drive. The motor field has a current regulator consisting of an exciter and an amplidyne, with both coarse and vernier rheostats controlling the excitation. Hence the speed of the fifth stand can be controlled relative to previous stand motor speeds and thus adjust outgoing steel thickness by varying tension between it and stand 4.

Once again, an x-ray gage measures the finished strip and originates an error signal that is judged for direction and magnitude by a transistor discriminator. This time the polarized signal is increased by a transistorized amplifier to a power level suitable for the field current regulator of the motor.

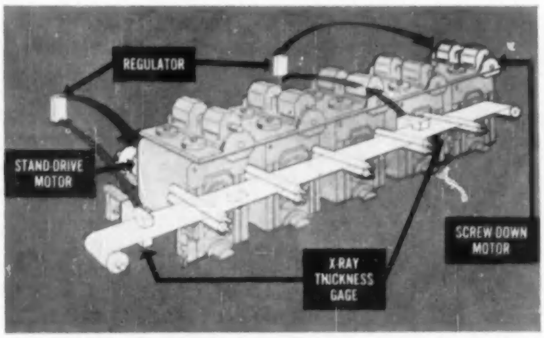
In operation, the coarse and vernier setting of the motor-field current regulator of the gage system are set to desired output thickness. Control then operates over a range of plus or minus 5 per cent speed. Changing the speed of stand 5 relative to stand 4 changes the draft and tension on the strip between the two stands to effectively control the thickness of the delivered steel.

Special auxiliary functions were also necessary in the vernier control system. Since the regulator range is limited to prevent looping or breakage of the strip, the system automatically is placed on manual when this range is exceeded and the operator warned of the fact by signal light. A "regulator inspector" function also operates at this stage of the system.

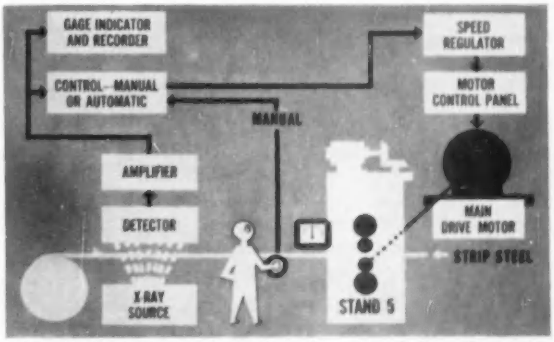
A Team of Nine Transistors

Perhaps the most newsworthy aspect of the new regulating system is its complete reliance on transistor and magnetic-amplifier techniques in circuits and components. Only nine transistors are actually required, but G-E's Iron and Steel Manager Bill Miller claims, "This is one of the first instances where transistors have been used to control main drives of 3,000 horsepower. We are confident that this is the system of the future."

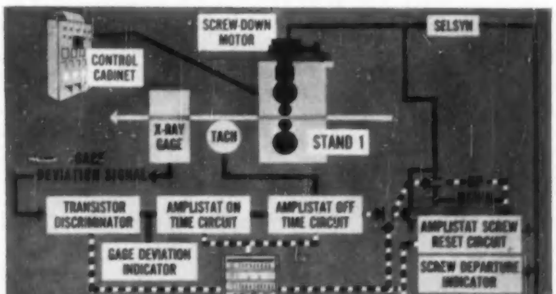
FOUR CLOSE-UPS OF MILL CONTROL FUNCTIONS



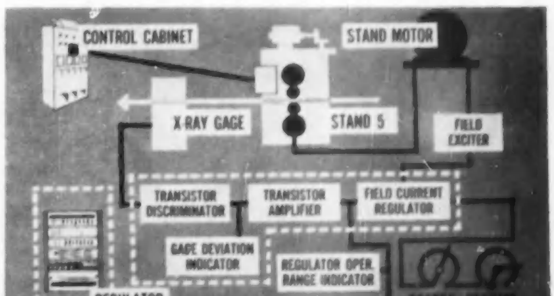
THE MILL consists of five roll stands and a tension reel arranged in a continuous line. One main drive motor powers all stands.



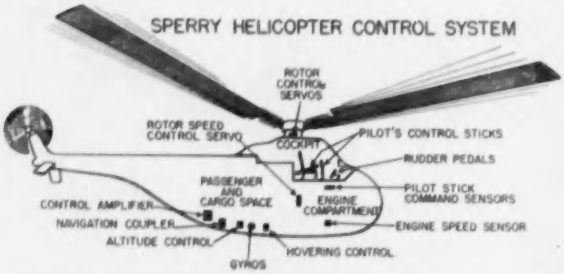
X-RAY GAGES are located with source below the steel strip and detector above. Error signals due to deviation actuate the regulating system.



COARSE CONTROL is effected by automatic positioning of the rolls on stand 1. This stabilizes the thickness of incoming steel to the mill.



VERNIER CONTROL is accomplished by regulating the speed of stand 5 relative to stand 4. The varied tension changes strip thickness.



TRANSISTORS IN A WHIRLYBIRD, TOO . . .
Sperry Gyroscope's new miniature, fail-safe, flight control system for helicopters includes automatic trim devices, altitude and speed controls—yet weighs only 60 lb. It's all due to transistorized module design and neat little linkages like the force sensor being pointed at in the test set-up. The system permits unmanned cargo operation.

CONTROL CONCLAVES

Chicago, Nov. 14-17

This was a busy week in Chicago for a visiting control engineer. If he happened to belong to ASME he was there for the Diamond Jubilee annual meeting and lost in a mass of 4,500 loyal conventioneers. But he found his control kin—he judged there were several hundred of them—at three excellent IRD sessions. The IRD papers this year were concerned with control valves, and our visitor reports good content and keen interest—particularly in papers given by Gorrie and Gantz on Design Limitations and Shearer on Nonlinear Characteristics. The highlight, however, was the 16-man panel of speakers at the end of the program which lunged and parried with questions raised by the sessions. Leaving the sessions our engineer stretched his legs at what he felt was a rather lackadaisical Power Show in the Chicago Coliseum. "Too small, too gloomy, too dismally remote," he reported.

A brighter, more specific show beckoned the control engineer to the Lake Shore's Navy Pier during this same week. There he became one of 10,000 attendees at Richard Rimbach's Second Automation Exposition. Filling about half the space of the vast pier, the booths' contents ranged from a large flock of counting and digital devices, through three big automatic logging systems, to industrial timers, relays, and components for what our man called "Detroit automation". The visitors, he thought, were also mainly out of the production engineering mold. But they were obviously good men and there to seriously look. Try as he might, he could not, however, find one central theme that characterized the show.

Early in this busy week our Chicago visitor made a special point to subway down to the Shoreland Hotel and the University of Chicago's two-day session on "Automation for Senior Officers". Here, while the papers were impressive (mainly about automation from a planning and policy standpoint) he was more impressed with the 200 top executives who took two precious days and paid the $150 fee to get this academically-organized briefing. "The average annual income of the people there," he estimated, "was about $20,000. Add that up and I was sitting amidst a group representing about $2 million in annual salary. What was I doing there?"

Los Angeles, Oct. 28

On this day our West Coast reporter joined a group of 300 in the Gold Room of the Ambassador Hotel to take in the 6th Annual Systems and Procedures Conference. This year the accent was on electronic data processing and its meaning to systems-minded management. Dr. Gene Grabbe, CONTROL ENGINEERING's West Coast consulting editor, keynoted the technical part of the program with a graphic rundown of the capabilities of the new technology. He cited experience with a large scale computer in his own company, the Ramo-Wooldridge Corp. "Our productive machine time," said Gene, "averages better than 90 per cent of a 40 hour week. This is equivalent to having 25,000 operators with desk calculators working for 40 hours." Even factory-expanding Ramo-Wooldridge, Gene tell us, could hardly stack such a staff vertically under its roof—much less in a normal maze of floor-bound desks. Dr. Grabbe predicted that the major future for computers "clearly lies in the interest and intent of business operations."

New York, Oct. 20-21

Our visiting control engineer also managed to nestle himself among the several hundred people from industry, government, and schools who attended the Second National Meeting of The Institute of the Management Sciences on two bright October days in Gotham. TIMS is devoted to promoting Operations Research and stresses the application of mathematical and scientific techniques to industrial problems—not to be confused with ORSA (Operations Research Society of America) which concentrates more on military problems. The sessions, he reports, covered a wide area. Gil Dantzig of the Rand Corp., Abe Charnes of Purdue, and W. W. Cooper of the Carnegie Institute discussed various extensions of linear programming, which they played a large part in originating. Other papers: Kircher of the University of California on the use of computers in management; Lieberman of Litton Industries on a mathematical model for

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WHAT'S NEW

business systems, Ackoff of Case on forecasting. Our reporter concludes, "The scope of the 30 papers was impressive, but sometimes left the listener doubtful as to the connection between the theoretical methods which have been developed and the practical steps which have actually been taken. As one of the speakers, Professor Kircher, observed, it may be that the usefulness of operations research has been due more to the influx of scientifically trained men into management fields than to the actual use of complicated mathematical techniques in solving managerial problems."

Boston, Nov. 7-9

Up in the scholarly clime of Back Bay our peripatetic control engineer spent a vigorous three days listening to 19 papers on the use of "computers in business and industrial systems" at the fifth annual Eastern Joint Computer Conference sponsored by AIEE, IRE, and ACM. About 1,000, he reports, jammed the ballroom and meeting rooms of the Statler Hotel—"keen, high-level people from an amazing variety of industries and businesses". The papers were very practical and obviously aimed at prospective users of digital equipment. One good example: a rather lively (rather slanted, too) discussion on the special purpose vs. general purpose computing system. But our man reports this general audience criticism: "There was too much stress on the immediate cost benefits of computers and not enough on the management decision function with its benefits."

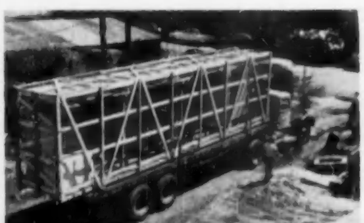
CONCLAVES TO COME

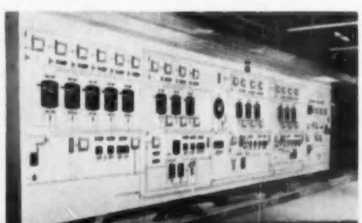
Princeton, Dec. 29-30

This year the Industrial and Engineering Chemistry Div. of the American Chemical Society will direct its Christmas Symposium to "Transient Chemical Process Behavior and Control". A good share of the interesting program will be devoted to the new tools of synthesis and dynamic analysis of process and plant and CtE editors Bill Vannah and Lloyd Slater will try to project the crusading zeal of their magazine into the opening address, "Process Control Enters a New Era". Besides this editorial-type keynote there will be some solid contributions from people out in the plants and by pioneering systems engineers from the instrument companies (i.e., Berger and Short of Phillips Petroleum on control characteristics of a pentane fractionator; Franks and Worley of Brown Instruments on quantitative analysis of cascade control). With at least two editors in attendance, our February issue will be sure to carry a full report on the ground that will be covered.

Heidelberg, Sept. 24-28, 1956

Professor Thomas J. Higgins, our prolific book reviewer at the University of Wisconsin, writes that a very soundly conceived German symposium on the "Value and Theory in Applications of Control Engineering" will take place next fall at the New University of Heidelberg. The program is subdivided into four main sections: 1) Concept of Theory—its Value and Efficiency; 2) Application and Limits of Elementary Procedures; 3) Mathematical Methods for Solving Control Problems; 4) The Outlook. Those due for a trip to Europe—or verging on a good paper that would fit this program scope—should write to Dr. Otto Grebe, Verband Deutscher Elektrotechniker e.V, Osthafenplatz 6, Frankfort on Main, Germany.





MONSANTO GETS MAMMOTH ONE-PIECE PANEL This five-ton, 33-ft-long unit, said to be the largest demineralization control panel ever built, made the trip from Texas City in one crate by truck and sea train. Bogue Electric Co. constructed it in only five months.

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MR-6-20	4-8	0-30	MR-6-100	4-8	0-120
MR-12-10	6-15	0-15	MR-12-50	6-15	0-70
MR-28-5	16-32	0-7.5	MR-28-20	16-32	0-30
MR-150-1	130-175	0-1	MR-150-5	135-175	0-5
MR-300-0.5	270-330	0-0.5	MR-300-3	270-330	0-3

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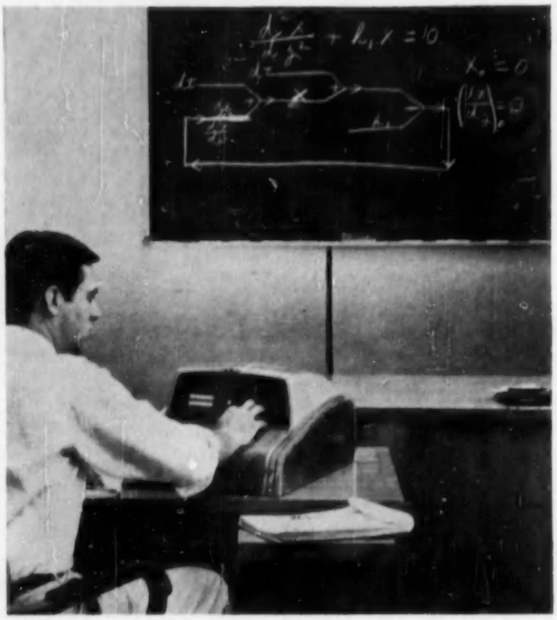
Five Digital Advances from the West

It may be the climate, or it may be their nearness to the Creative Vortex of the Communicative Arts (Hollywood). But for sheer fecundity in new ideas and products the California Digital-Data Developers have few peers. Witness these five new offerings which first saw light this past November.

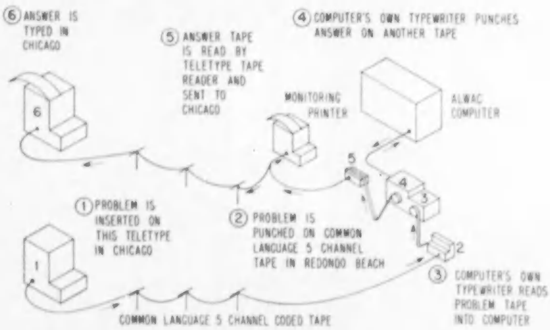


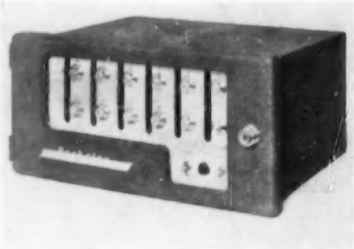
1. A PORTABLE DIGITAL DIFFERENTIAL ANALYZER

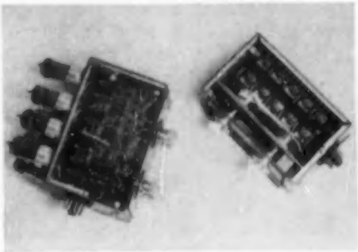
The neat little typewriter-sized box on the engineer's desk has a rather lofty price for the space it occupies (its maker, Litton Industries, suggests the $10,000 range). But the price seems small when you consider the jobs it can do. Take the problem on the blackboard for example. Just a few flicks of the finger and the answer will come up on the little picture tube in the corner of the panel. No, it's not a closed loop to Norbert Wiener—this new device is a digital differential analyzer that packs twenty integrators, each accurate to one part in 250,000. It can handle any mathematical problem that can be put in differential form—does it by an iterative process that is completed 60 times per sec. The integrations, of course, must be preprogrammed. The tiny machine operates on 110 v and requires only 300 watts. It has plug-in components and a small magnetic memory. It can generate arbitrary functions and is easily coded to produce limiting or decision functions. As a matter of fact, its makers claim that it will tackle most problems normally relegated to the electronic analog DA—and goes the latter one better by handling equations that can have variable dx and/or dy inputs to each integrator.

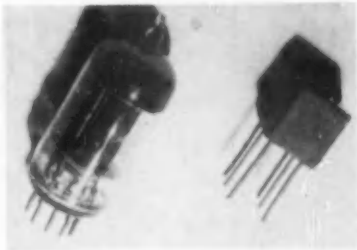
2. A LONG-DISTANCE COMPUTING SERVICE

The telegraph poles in the little sketch at the right—stretching 2,000 miles from Chicago's Navy Pier to Logistic Research's neat plant in Redondo Beach, Calif.—carried strange signals on Nov. 15. The pulses originated from complex rows of figures punched into a Teletype machine in the company's booth at the Automation Show (see page 20 for show details). They sped cross-country and fed into an Alwac computer at the plant. Seconds later a new group of figures—the computed answer—were neatly typed in the Chicago booth. Spectators at the show tried mortgage data, pet problems, amoeba-in-bucket gambits. The answers came back almost as the last number was entered. The desk at the right holds the plant's transmission and receiving equipment—a Western Union teleprinter machine using a 5-channel common language tape and a Flexowriter. In the background is the Alwac computer which converts the Teleprinter's 5-hole tape to 6-hole code, works the problem, then sends it to the Flexowriter again in 5-hole form. The resulting tape is read by a Western Union transmitter in California, then printed in Chicago. The company believes small laboratories and business will find this service will bring digital problem-solving well within their budget.









3. A SOLID-STATE REDESIGN FOR A COUNTER

The handsome dual pre-set electronic counter, above left, on the surface looks like a more compact and functional design of the company's well-known line. But get inside the case and you'll find a small new decimal counting module replacing the standard vacuum tube version—see the substitute in the center picture. The picture on the right reveals how it's done. The Berkeley Div. of Beckman Instruments has gone over to Carl Isborn's "Ferristor"—the new solid-state vacuum tube substitute discovered by this engineer for Berkeley early this year. The "Ferristor", actually a caramel-sized magnetic amplifier, handles all former tube functions: input amplifier, memory, gate, and relay controller. Besides savings in space and power, the circuits should bring much more reliability to industrial counters. With the exception of speed, most of the other characteristics of the new magnetic EPUT counter equal, if not exceed, the old vacuum tube model.

4. A COMPACT GENERAL-PURPOSE DIGITAL COMPUTER

The deceptively simple freezer-sized cabinet flanking the girl is actually the whole part-and-parcel of a new Librascope general purpose digital computer. Pull off the steel cover, however, and you'll find a beautifully compact three-section system on wheels: sliding drawer logic boards; a plug-in card section containing 100 vacuum tubes and 1,300 diodes; a magnetic drum memory. Also "under the hood": complete air conditioning and a self-contained power supply. The computing capabilities match the neatly designed innards. The machine will handle a 30-bit word length, plus sign and buffer. It has a 4,098 word capacity and a 3,600 rpm access speed. Its average access time is 8.5/1,000 sec.

5. AN AIRBORNE DIGITAL COMPUTER

The benchbound collection of wafers that the young man is investigating has just come back to earth after a highly successful flight test for function by its developer, North American Aviation's Missile and Control Equipment (MACE) Operations for the U. S. Air Force. Get closer to the thing, circle it, and you'll find it is a digital computer, completely transistorized to occupy only 3 cu ft and weigh only 125 lb. Further, to accomplish its function of processing in-flight data, it uses less than 100 watts power. A similar vacuum-tube computer with one-half the capacity would consume 3,000 watts. Etched circuits on copper clad plastic are also weight and size savers. Some 1,000 transistors are held on 51 of these standardized panels, which pull out like file cards for testing and replacement. The computer is able to integrate 93 quantities simultaneously and can generate continuous solution of differential and trigonometric problems.

ALL THIS, AND AN AIRFIELD, TOO. Connected to Massachusetts' Grenier airfield by a short stroll is this new, half-million-dollar plant of Marion Electrical Instrument Co. The single-story, 40,000-sq-ft facility produces more than 80 per cent of all Marion components. The company's field-based plane provides quick access to all customers.

All Around the Business Loop

▶ Two manufacturers of control instruments have wound up their fiscal years in style. Figures are somewhat misleading in the case of **The Perkin-Elmer Corp.**, because slight declines in net sales and net income (down $67,422 and $55,055 respectively) far from tell the whole story. P-E's president and board chairman, Richard S. Perkin, reporting on the year that ended July 31, noted that shipments of commercial analytical instruments reached a record level of $3,784,643 and that new orders for such instruments increased 16 per cent over fiscal 1954. Military sales (40 per cent of P-E's business) reacted according to expectations and it was this anticipated lag between successive defense production contracts that accounted for the dip in net sales. New orders in all categories rose to $7,743,000, a 32 per cent increase over the previous year, and increased the backlog to $6,818,000. These figures, of course, reflect operations prior to the October flood, which Perkin-Elmer weathered so meritoriously (see December issue, page 28).

▶ **Varian Associates**, in its report covering the year ending Sept. 30, noted that for the first time in its history sales of industrial and scientific instruments and electronic systems exceeded 8 per cent of total sales. In fact, products in this class produced nearly one fifth of the entire volume. The klystron vacuum tube, the company's best known product, accounted for 82 per cent. Dollar figures were: sales up $1,259,000, backlog up $2,435,000, and net earnings, at the end of the year, $433,000. Included in the consolidated figures is $19,000, the profits from the new subsidiary, **Varian Associates of Canada, Ltd.**, which recently finished its new home in Georgetown, Ontario. Varian plans to spend close to $500,000 in this fiscal year on new product research.

▶ Other companies have submitted bright reports for the first nine months of calendar 1955. Among them: **Thomas A. Edison, Inc.**, with consolidated profits after taxes of $900,162, up 80 per cent or $399,289; sales of $26,038,159, up $497,596, and net earnings of $328,784, up $287,514; and **General Controls Co.**, with sales of $19,249,458, more than for all of 1954, and net earnings of $1,156,664, up $439,391. President W. A. Ray expects total gross sales for 1955 to hit $27 million, which would be an all-time high for the Glendale, Calif., company.

▶ **Fairchild Camera & Instrument Corp.** has brought in one of the Navy's top nucleonics experts to head its new **Nuclear Instrumentation Dept.** Being considered for development and manufacture by Dr. Harold E. DeBolt's unit are radiation monitoring equipment, control rod drive mechanisms for atomic reactors, neutron detectors, and associated temperature, pressure, and flow controls. These packaged reactor controls will be designed primarily for commercial applications, but to some degree, too, for the military. One outlet in the latter category: the Aircraft Nuclear Propulsion Program of the Air Force's Air Development Command. DeBolt most recently was with the Nuclear Power Div. of the Navy's Bureau of Ships and the Naval Reactor Branch of the AEC's Reactor Development Div.

▶ In its **Arizona Research Laboratories** in Phoenix, **Motorola** is producing the new very-high-frequency diffused base transistors on a pilot-plant basis. This is the first announcement of any successful venture into commercial production of the new transistor since its development by Drs. William Shockley and George Dacey of the **Bell**

Telephone Laboratories, and is one of a pair of announcements to be made by Motorola. The other: the company is getting set for semi-automatic manufacture of the transistor. The diffused base technique permits production of transistors for frequency ranges as high as 1 billion cycles per sec, at which range they are applicable to every kind of communication system. It will be two or three years, however, before this general application becomes practicable, Motorola's vice-president, Daniel E. Noble, believes.

► Two upstate New York cities figure in the formation by **IBM** of a new **Military Products Div.,** whose general manager is Charles F. McElwain. At Kingston, General Manager Gavin A. Cullen will direct IBM's part of Project Lincoln, a government effort involving production of ground-based computers for the continental air warning network. MIT is collaborating with IBM on this project. And at Vestal, near Binghamton, the second area of the new division is taking shape under Curt I. Johnson. Participating at Vestal are Johnson's **Airborne Computer Laboratory** and production facilities for advanced electronic bombing and navigational systems. McElwain, formerly director of defense engineering and manufacturing, will supervise operations from administrative offices in New York City. The new division now holds the same autonomy as IBM's **Electric Typewriter Div.**

IBM isn't telling what kind of machine it's developing and producing on a pilot basis at San Jose, Calif. It has revealed, however, that it has leased a 20,000-sq-ft building for the project and that work is already under way.

► Service facilities for handling electronic instruments are being expanded across the U. S. by **Allen B. Du Mont Laboratories, Inc.** One big reason for the move is that the company now is marketing a number of general-purpose electronic instruments and engineering a new line of cathode-ray oscillographs. Du Mont plans to put the **Technical Sales Dept.** under a dual administration, service to be headed by F. William Scharpwinkel and parts sales by Rudolph H. Arp.

Du Mont's new West Coast headquarters plant, which recently went into operation in Los Angeles, gave the company six times as much space as its former facilities there. Included are 30,000 sq ft of working space, a railroad siding, and a parking area.

WHAT'S NEW

► The complete engineering and design file of **Stockwell Transformer Corp's** liquid-filled and air-cooled transformers has been purchased by **Precision Transformer Corp.** The range of these transformers is to 3,000 kva.

► Under a new agreement, **Ohmite Mfg. Co.** will produce the Amrecon relays formerly made by **American Relay & Controls, Inc.,** at one time a subsidiary of Ohmite. They'll take on the new name of Ohmite Amrecon relays and will continue to emanate from Ohmite's plant in Skokie, Ill.

► When an exchange of shares between **Link-Belt Co.** and **Syntron Co.** has been consummated, Syntron will become a Link-Belt subsidiary.

► On the way up: a new manufacturing plant—157,000 sq ft—in Syosset, Long Island, for **Kollsman Instrument Corp.,** to be completed next fall; and an addition—44,000 sq ft—to **Beckman's Berkeley Div.** in Richmond, Calif., to be completed by the middle of this month.

► Opened: a three-story plant (33,000 sq ft) in Bristol, Pa., by **Bristol Engineering Co.;** a subsidiary plant (12,000 sq ft) in Ames, Ia., by **Bourns Laboratories;** a new facility **(Timely Instruments & Controls Corp.)** in Gardena, Calif.; an eastern regional sales office in New York City by **Texas Instruments, Inc.;** and a west Coast office in San Francisco by the **Research & Control Instruments Div.** of **North American Philips Co., Inc.**

► Recent acquisitions: **Phebco, Inc.** (electronic equipment for industrial use; radar and guided missiles) by **Hoover Co.,** which with this step extends operations beyond the field of household cleaning appliances; and **Farris Stacon Corp.** (temperature control valves) by **A. W. Cash Co.**

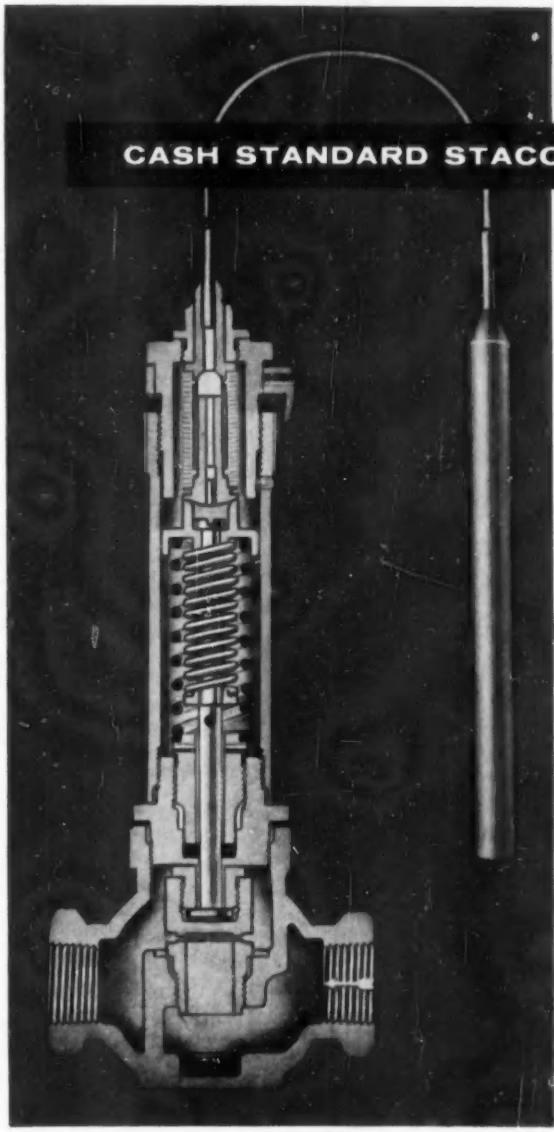
► And a merger: **Electric Controller & Mfg. Co.** and **Square D Co.**

TECHNICIANS ABROAD Marty Ladden—Brown Instruments' energetic education director—points out features in the ElectroniK to students in Minneapolis-Honeywell's new training school at Perivale, England.

Cash Standard Expands

by the addition of

Stacon Temperature Regulators

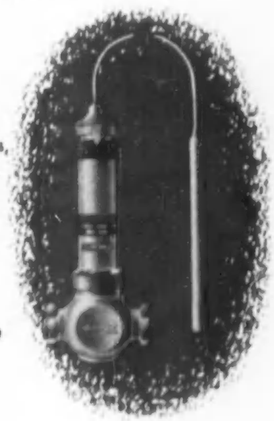


This line of temperature regulators (formerly manufactured by Farris Stacon Corp.) rounds out complete Cash Standard line of valves to solve any problem of temperature regulation or pressure control.

CASH STANDARD STACON TEMPERATURE REGULATORS

- Provide accurate temperature control for use with steam, liquids and gases.
- Self-operating and self-contained pilot-operating.
- Direct and reverse acting.
- Liquid filled thermal system for high operating power and uniform throttling action.
- Extremely compact construction with rugged field-replaceable thermostatic system.
- Overload protection to prevent overstressing of thermostatic system at over-range temperature.

Recommended for hot water heaters, tanks, kettles, plating tanks, bottle and can washers, degreasers, ovens, fuel oil heaters, brine circulating, process cooling, jacket cooling for compressors, diesel and gas engines, and many other uses.



What Is *Your* Temperature Regulation Problem?

Cash Standard has the Answer!

Contact your Cash Standard control specialist or write Dept. F.

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A. W. CASH COMPANY, P. O. Box 551, Decatur, Illinois

Pressure, Hydraulic, Temperature, Process and Combustion Controls

L. L. Wheeler

Raymond Meyer

W. C. Norris

M. L. Rice

Joseph Tampico

Arnold Raines

Important Moves by Key People

▶ **Dr. L. L. Wheeler** is the new chief engineer of Sperry Gyroscope Co. A specialist in weapon system engineering, he directed the project that resulted in today's K-bombing navigational system. He has been assistant chief engineer since 1951. Leaving the post of chief engineer for that of vice-president for research and development is **Dr. W. L. Barrow,** who was an associate professor at MIT before joining Sperry in 1943. Barrow, who became vice-president and chief engineer in 1952, directed a number of wartime projects in fire control and armament engineering. He has been an advisor to the armed forces for the past 14 years. **George A. Richroath,** who has been named vice-president of manufacturing, leaves his works manager post to **Samuel Agabian.** Mr. Richroath joined the Sperry Gyroscope Co. in 1941. Agabian in 1940.

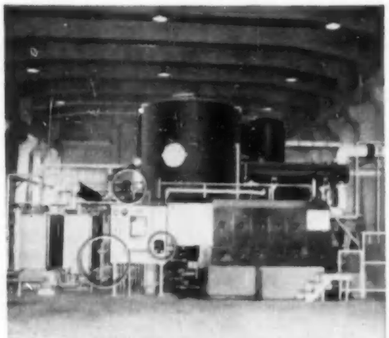
▶ Acting on the advice of economists, who see big gains for its production facilities, ElectroData Corp. has established a new post, that of supervisor of manufacturing, and filled it with **Raymond Meyer,** formerly administrative assistant to the vice-president. Meyer moves into the job as ElectroData prepares for a major expansion in output: three complete Datatron computer systems a month, starting this fall.

▶ When **William C. Norris,** vice-president of Remington Rand, became general manager of the new Univac Div., these facilities were consolidated under his supervision: the Eckert-Mauchly Div. at Philadelphia; the Engineering Research Associates Div. at St. Paul, the Tabulating Div., and the Laboratory for Advanced Research at Norwalk, Conn. All electronic computer and tabulating machine operations have been funneled into the new division, for which a 200,000 sq ft electronic laboratory will be built in St. Paul.

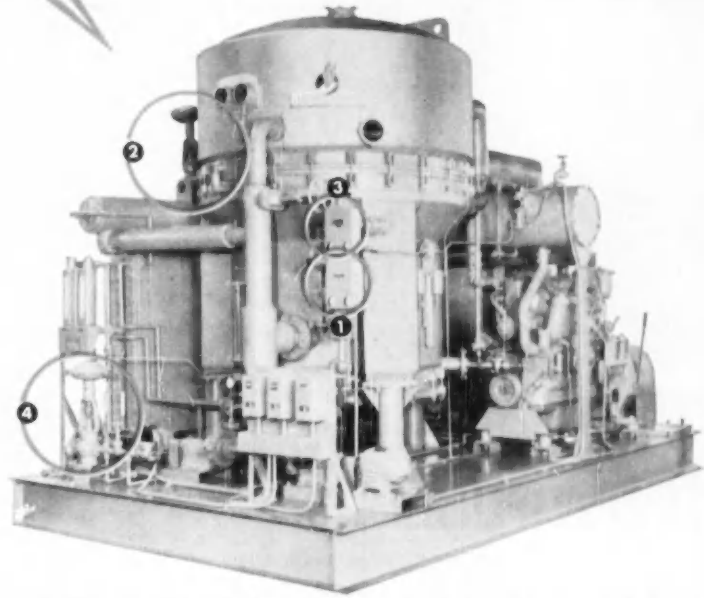
▶ Atlantic Research Corp. has brought its Applied Mathematics and Interior Ballistics Project Group "up from the ranks" and made it a division. Director is **Millard Lee Rice,** who joined the staff in 1950 and has been director of the unit since its formation as a group in 1954. At the same time a new Technical Information and Library Planning Group has been organized under **Saul Herner,** technical information specialist. The group will consult and do research in technical information and communication.

▶ Associated Missile Products Corp., the eight-months-old subsidiary of American Machine & Foundry Co., has named **Dr. Joseph Tampico** di-

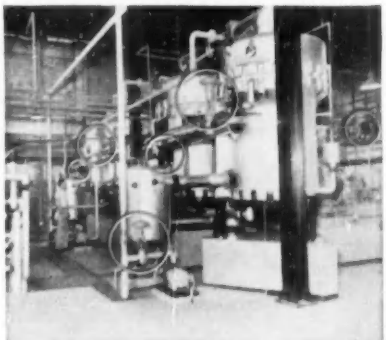
This Cleaver-Brooks Unit Converts –
SEA WATER INTO FRESH WATER



At the time of its installation at the Kindley Air Force Base in Bermuda, this Cleaver-Brooks unit and three others like it constituted the world's largest vapor compression sea water distillation plant. Total daily capacity of the installation is more than 200,000 gallons. BS&B Automatic Controls are standard equipment on all units.



This Cleaver-Brooks Diesel Drive Compression Still produces more than 14,000 gallons of U.S.P. chemically pure and pyrogen free water per day from brackish or sea water. It is automatically controlled by (1) a BS&B Type 1400LP Low Pressure Pilot which operates (2) a BS&B Type 86R Valve to control the evaporator pressure, and by (3) a BS&B Type 887 Liquid Level Controller which operates (4) another BS&B Type 86R Valve to control the evaporator liquid level.



Largest compression still installation in the United States for producing distilled water is this West Coast metropolitan area plant which commercially produces more than 100,000 gallons of distilled water daily. All units are Cleaver-Brooks. Note BS&B Automatic Controls visible in the picture.

. . . With The Help Of
BS&B AUTOMATIC CONTROLS!

When a manufacturer of heavy industrial heating and process equipment selects the automatic controls to be used as "original equipment" on his units, he must be *certain* that they will operate just as efficiently and dependably as the unit they are to serve.

That is why Cleaver-Brooks Company, of Milwaukee, and many other manufacturers have standardized on BS&B. They know that BS&B Automatic Controls can *always* be counted on for precise accuracy, superior quality, long life and outstanding performance!

Why not make BS&B Automatic Controls your *first* choice too–both for "original equipment" and for replacements? Your BS&B Representative will be glad to give you detailed information. Or you may write to . . .

EFFICIENCY
OVER 50 YEARS
BS&B
RELIABILITY
ANOTHER EXAMPLE OF PRODUCT LEADERSHIP

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Controls Division, Dept. 4-ES1

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rector of engineering and **Earl R. Skaggs** assistant general manager, a new position. Tampico, a vice-president, has been director of research, and Skaggs, also a V-P, formerly was director of product engineering.

▶ The two men who have taken charge of Norden-Ketay Corp.'s new Western Div. at Gardena and Hawthorne, Calif., were both formerly with the Arga Div. of Beckman Instruments, Inc. They are **Arnold Raines,** general manager, and **Herbert Galman,** manager of the Engineering Dept. Plants at the two cities will carry out research, engineering, development, and sales and service on a completely self-sufficient basis. N-K's manufacturing operation in California has been integrated into the new division.

▶ **Perry C. Smith,** the new manager of the Equipment Dept. of Clevite Corp.'s Brush Electronics Div., was general manager of the Electronics Instruments Div. of the Burroughs Corp. before joining Brush early in 1955. Prior to that he was manager of scientific instruments engineering for RCA. Clevite Research Center, which does research and development work for all Clevite units, has named **J. Kneeland Nunan** to the new position of vice-president and general manager. Nunan, who most recently was president of Consolidated Vacuum Corp., has built up an impressive background as a result of experience with the following organizations: Consolidated Engineering Corp., Hughes Aircraft, Trans-World Airlines, Ansco Div. of General Analine & Film Corp.; Aerojet Div. of General Tire & Rubber Co., Navy Underwater Sound Laboratory, and the scientific staff of the Div. of War Research at Columbia University.

▶ **Seymour Blechman** brings 15 years' experience in flow measurement and control to his new post of executive vice-president of Brooks Rotameter Co., where he will coordinate and guide product improvement and expansion. Most recently he was with Fischer & Porter Co. as vice-president and sales manager.

▶ When **Harold E. Carlson** moved from manager of the Eastern Div. of Servomechanisms, Inc., to program controller, **Gerard Q. Decker** took over at the Westbury, N. Y., division headquarters. As program controller, Carlson joins the executive office staff. Decker was formerly with Rheem Mfg. Co.'s Government Products Div.

▶ ESC Corp.'s high power pulse forming networks are unique in the industry, now that a brain has been added. To be specific, **Bernard Brain,** who as a department head, will have technical responsibility for design and de-

P. C. Smith

Seymour Blechman

G. Q. Decker

Bernard Brain

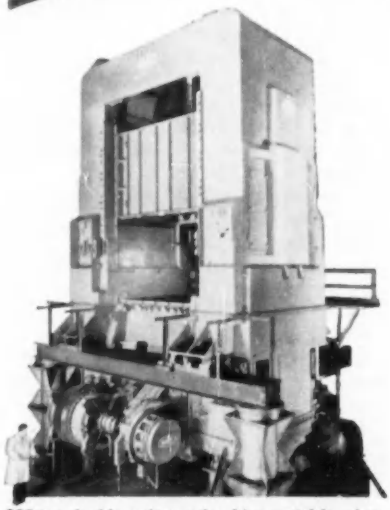
W. H. Kushnick

Oliver Mueller

DYNAMATIC®

EDDY-CURRENT EQUIPMENT

is Solving Speed Control Problems in Every Major Industry

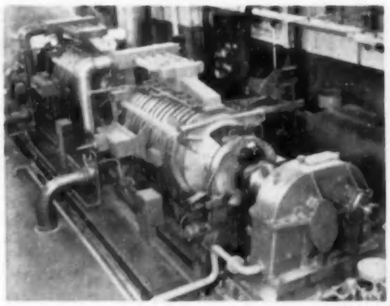


800 ton double-action under-drive metal forming press, driven by Dynamatic model 37-32 combination eddy-current coupling and brake.

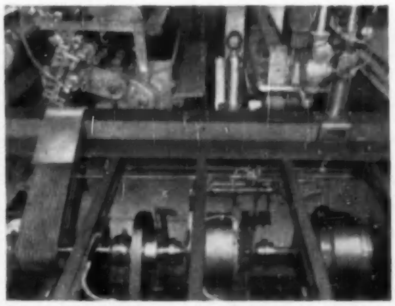
In practically all testing, processing, and conveying equipment common to industry, Dynamatic eddy-current rotating equipment is solving a wide range of adjustable speed drive problems, particularly where an AC power source is a requirement.

Advantages include rapid response, stepless adjustable speed control, wide speed range, quiet operation, low power loss, low maintenance cost, adjustable speed from an AC power source.

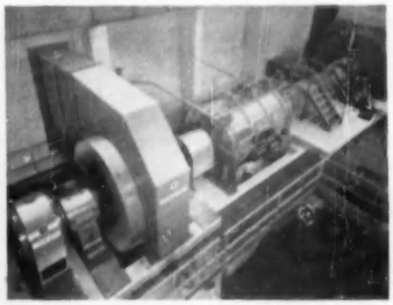
Send for Bulletin GB2, which describes and illustrates the basic Dynamatic eddy-current units, including couplings, brakes, dynamometers, press drives, and Ajusto-Spede® drives.



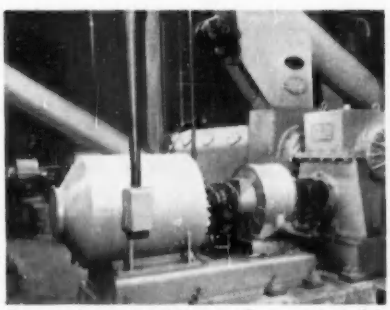
Tandem Dynamatic dynamometers, rated 20000 H.P., 600 to 5800 RPM. A cradled gear box permits turbine testing to 15000 RPM.



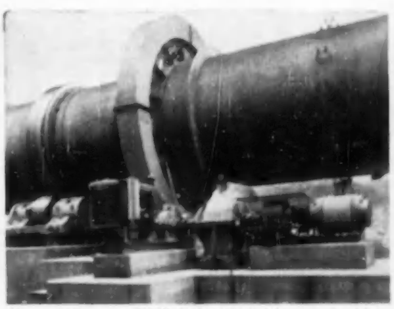
Model WC-1308 Dynamatic adjustable speed eddy-current coupling with eddy-current brake, used as printing press drive. Rated 20 H.P at 1700 RPM.



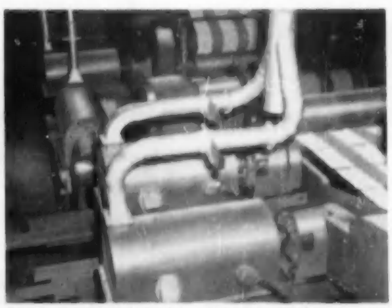
Dynamatic adjustable speed eddy-current aircraft wind tunnel drive, 18000 H.P. at 480 RPM.



Paper pulp washer driven by Dynamatic model WC-160 adjustable speed eddy-current coupling, rated 125 H.P. at 1100 RPM.



Dynamatic model WC-160 adjustable speed eddy-current coupling, rated 100 H.P. at 1100 RPM, used as cement kiln drive.



Roofing material machine driven by 23 Dynamatic Ajusto-Spede® drives. All drives and controls completely enclosed and force ventilated.

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velopment of the networks. Brain was instrumental in development of PTM communications systems by Federal Telecommunications Laboratories, with which he associated for 10 years.

▶ **William H. Kushnick**, executive director of ISA, has been appointed chairman of a special committee that will review the personnel recommendations made by the Hoover Commission on the business organization of the Dept. of Defense. Kushnick's appointment was made by that department.

▶ **Oliver Mueller**, who has been named chief engineer of the Aircraft Controls Div. of Gorn Electric Co., has been chief engineer of Fischer & Porter Co. and chief tool engineer of the Ordnance Div. of Bell Aircraft Co.

▶ Concurrent with the retirement of **Carl H. Bissell**, vice-president for engineering, these executive appointments have been made by Crouse-Hinds Co.: **Albert H. Clarke**, commercial vice-president, to succeed Bissell; **Jay R. Petree**, assistant chief engineer, to chief engineer, and **John R. Haney**, to succeed Clarke as manager of the Illumination Dept. Bissell, a pioneer in electricity, conceived the first automatic traffic signal controller and fostered development of Crouse-Hinds' explosion-proof electrical equipment for hazardous areas. He joined the company in 1901.

▶ Two research scientists, whose fields are principally physics, have been named associate directors of the Westinghouse Research Laboratories. They are: **Dr. Daniel Alpert**, whose work in ultra-high vacuum research culminated this year in coveted recognition by the American Association for the Advancement of Science, which stamped one of his papers the most noteworthy one presented at its session in Berkeley, Calif.; and **Dr. Aaron Wexler**, whose low temperature laboratory, established by him at Westinghouse in 1947, has received international acclaim for studies of electrical and magnetic properties at temperatures as low as a fraction of a degree of absolute zero. Alpert joined Westinghouse in 1941, Wexler in 1947.

▶ **Dr. Leland G. Cole**, who last year directed the dynamics laboratory of Robertshaw-Fulton Controls Co., has been named to the research staff of Consolidated Engineering Corp. At the same time **Kenneth Hines**, a research chemist formerly with Shell Oil Co.'s Houston refinery, joins the company as a project engineer in the Systems Div.

WHAT'S NEW

Flanking Dr. Joseph W. Barker, of ASME, are engineer-tourists Vladimire P. Loukine (left) and Georgi P. Kazanski, both of Moscow.

Soviet Control Engineers Unmoved by U.S. "Automation"

Whoever in our State Department labeled the two visiting Soviet control engineers "automation experts" made a sad mistake: as a result the two specialists were taken on a misguided two week whirl of standard big-plant facilities, with the accent on transfer and production rather than measurement and feedback.

At the press conference at tour's end, the Russian's comments could almost be predicted. When asked what they thought of the "highly automated" plants they saw, they replied, "We saw nothing new." And asked to name the most "interesting thing," the answer was, "The most interesting thing is that we did not see what we wanted to see."

The visiting engineers—V. P. Loukine of the Soviet Machine Construction Ministry, and G. P. Kazanski of the Radio Technics Ministry—were much more disappointed than ironic. Actually, they had nothing but praise for the ASME, who acted as their host on the tour. And for their reception across the land. But it was obvious that they knew that advances in the art of control did exist here and that their itinerary, arranged along "automation" lines, frustrated their chances to see these things.

Parallel Developments in USSR

At the press conference CONTROL ENGINEERING's representative attempted some questions about various aspects of control in USSR. Here are some of the comments he received:

▶ **Digital Computers** — apparently USSR has developed large numbers of large-scale digital computers. These are mainly being used in tackling scientific research problems and in statistical data processing. One recently developed Soviet computer is capable of solving differential equations of the sixth order.

▶ **Machine Control**—they saw no closed-loop or measurement techniques on U. S. machinery in their tour that has not its parallel in USSR. Apparently the Machine Construction Ministry is deep into continuous gaging problems.

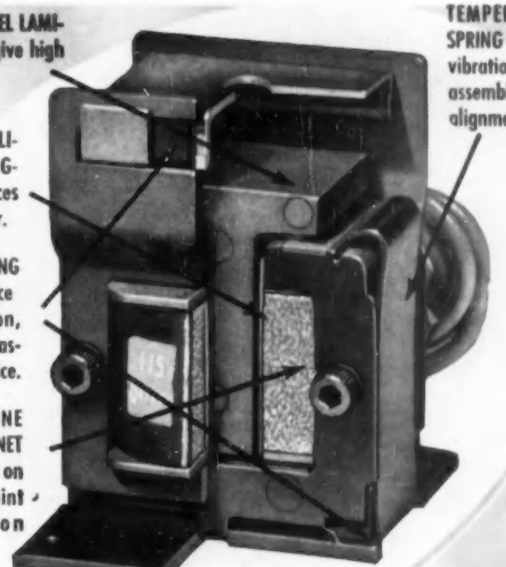
▶ **Solid-State Devices**—USSR was held to be at about the same level in development in using transistors and other solid state devices as the U. S. However, Mr. Kazanski indicated that Russian engineers were stressing this approach more in the design of industrial measuring equipment than in commercial communications.

▶ **Refinery Control**—one plant in the Russians' tour was the Standard Oil refinery in Cleveland. The control panels there did not impress them. They claimed that similar installations have been in USSR for the past 15 to 20 years.

▶ **Electronics in Control**—the visiting engineers estimated that about 20 per cent of all measuring apparatus in USSR control systems employed electronic techniques. They claimed that Soviet production of electronic equipment has gone up five-fold in the past five years.

It was apparent that the visitors were highly skilled engineers and very well steeped in control theory and application. Our editor, near the end of the conference, suggested that they return this spring for the IRE show, and next fall for the ISA conference. And for an industrial tour guided by trained control engineer.

the "inside" story!




HORIZONTAL PUSH-TYPE WELDED BASE


VERTICAL PULL TYPE SHOCK-MOUNTED


VERTICAL PUSH-TYPE WELDED BASE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In addition to all the "inside" advantages, Decco Solenoids are compactly designed and thoroughly impregnated with silicone baking varnish for high moisture resistance.

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This Bailey Armortube* Cable can save you time and money

With this new material especially designed for pneumatic connecting lines you can make better instrument and control installations in less time and at less cost. Here's why:

Simple Standard ARMORTUBE* cable is stocked in three convenient sizes: bundles of four, eight, or twelve ¼ inch O.D. aluminum alloy or copper tubes. Other sizes are available on special order. It's a ready-made, fully protected piping material for transmitting pneumatic signals between measuring units, instruments, and control units.

Safe The flexible metallic covering guards against every hazard, internal or external. Patented rope-like arrangement of tubes eliminates danger of collapse at sharp bends—and damage from external blows or vibration is minimized by protective outer covering.

Compact All necessary lines can be snaked through tight quarters or around corners with a minimum of connections. No need for unsightly, bulky channels, racks or other special mountings.

Economical Installation is fast. 100 foot coils and 500 foot reels permit long unbroken runs. Colored tracer simplifies connections at terminals. Slightly higher first cost is quickly amortized by savings in materials, and installation time. For further information and specifications ask for Bulletin and Price List G91-9.

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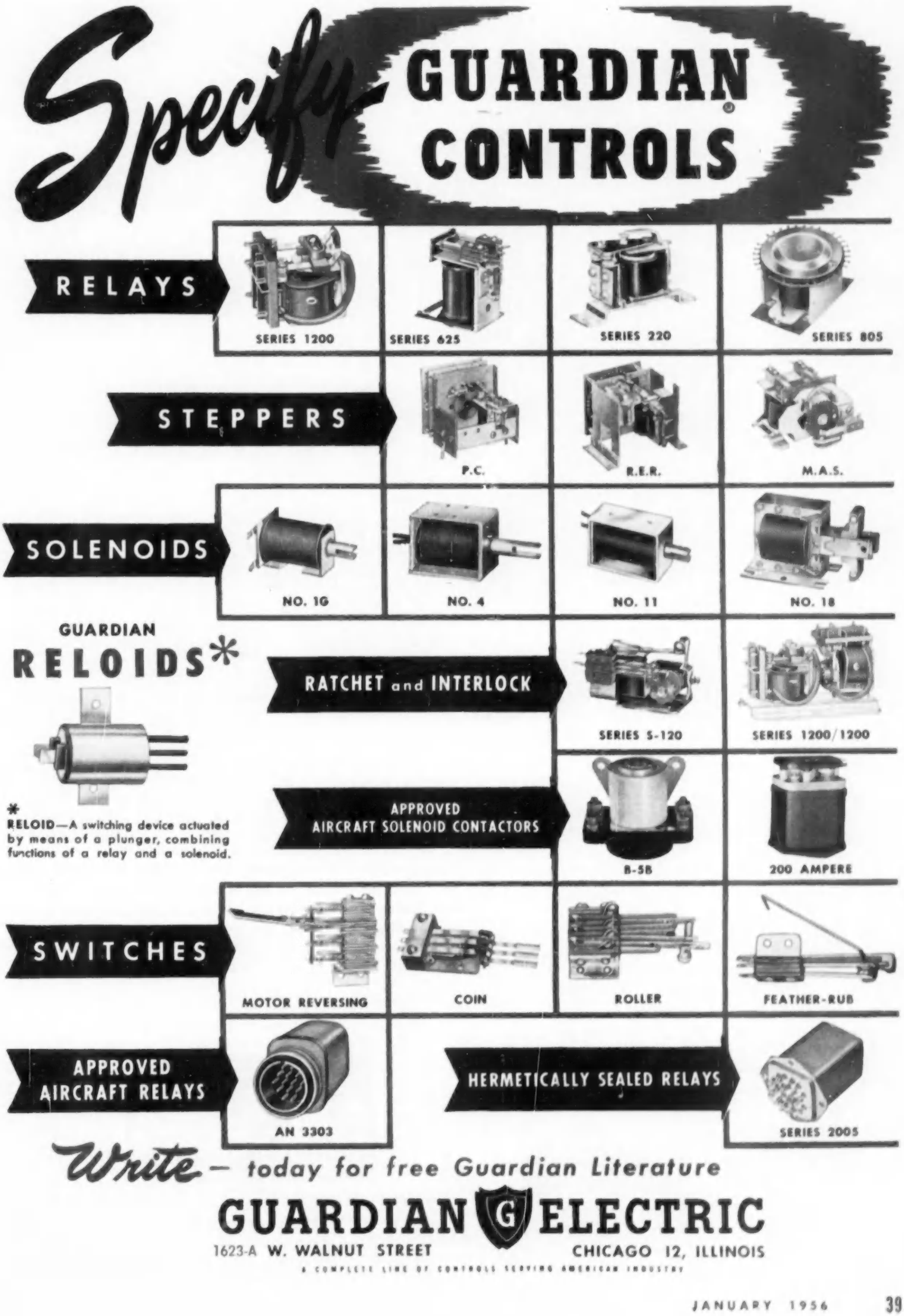
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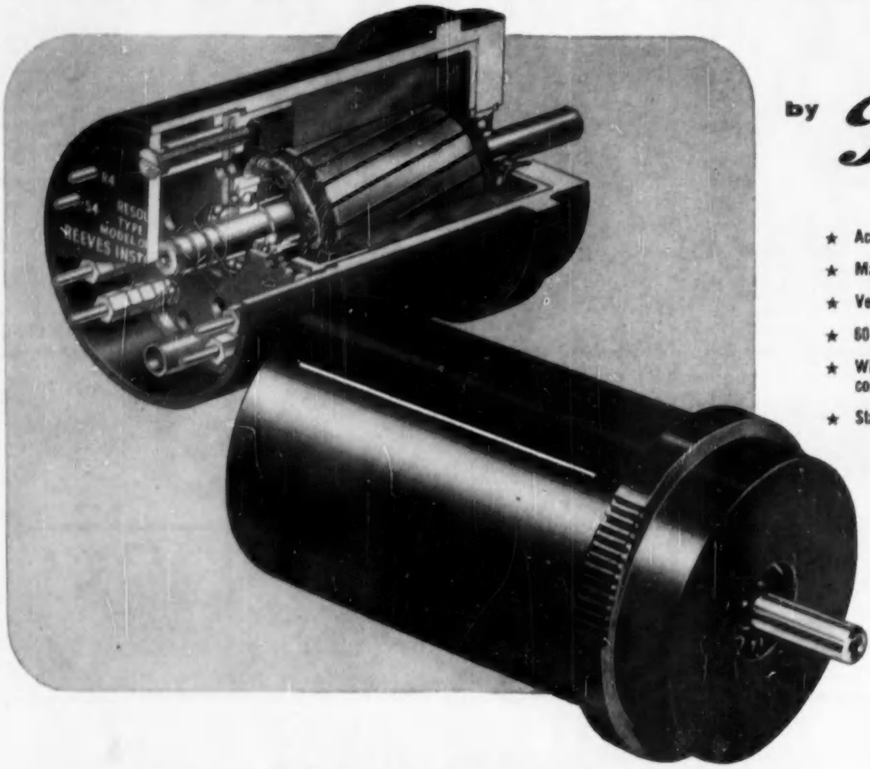

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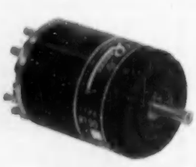

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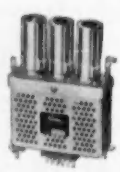

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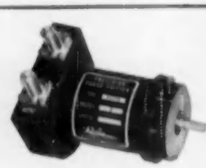

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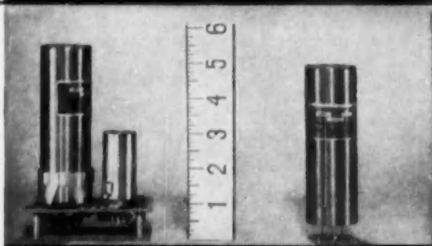

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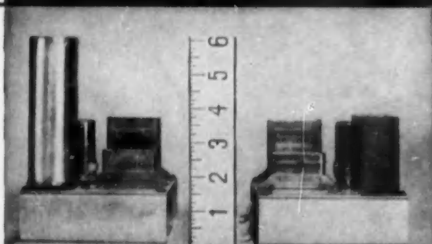

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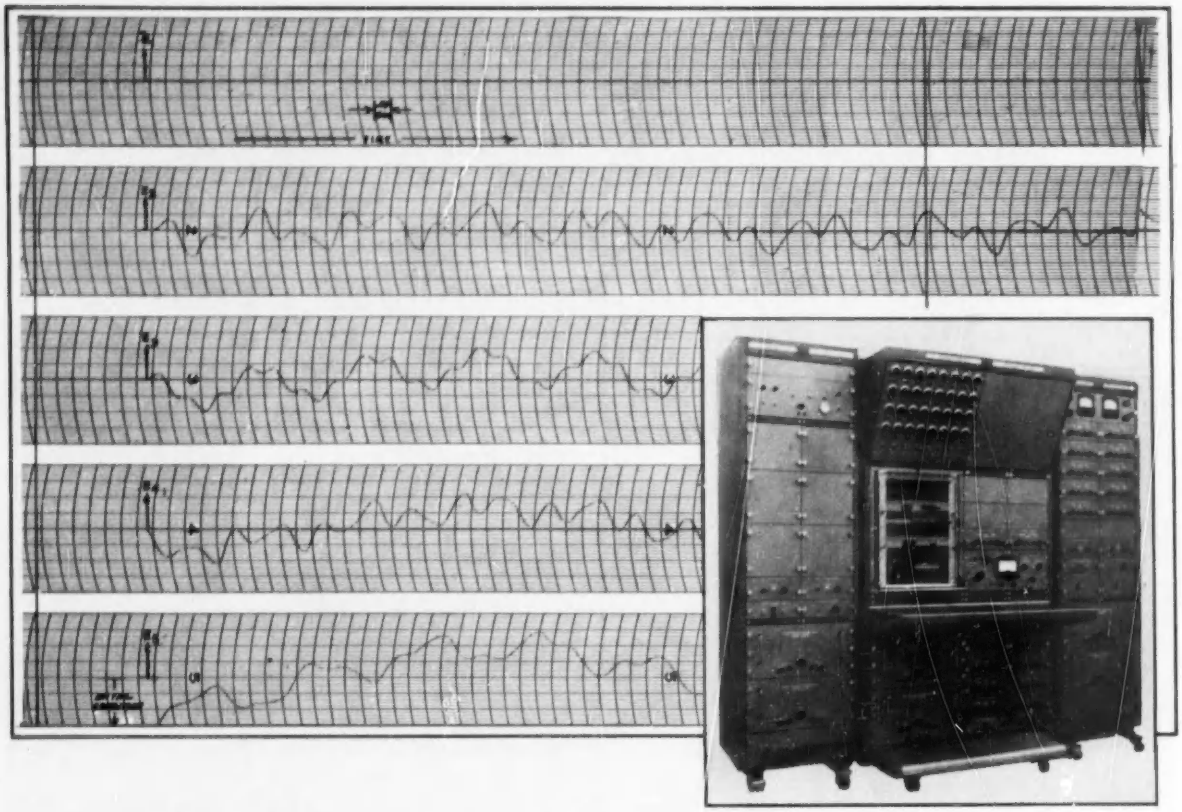

Application in structure dynamics and the unique building block expansion of EAI Computers . . .

An engineer was anxious to determine the vibration and stress of a beam, one end of which was to be solidly built into the support while the opposite end was to be unrestrained.

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Naturally, in a problem such as this, it is important that the engineer be able to obtain the degree of accuracy needed to meet his specific requirements. This can be done on EAI Equipment, for EAI's unique building block system makes it possible to expand the computer to meet your specific needs. Thus by making use of more computing equipment, the engineer was able to divide the beam into more sections of smaller size and obtain a greater degree of accuracy.

Such features as this unique buiding block system, problem checks, automatic readouts, and powerful amplifiers have earned EAI Analog Computers an unsurpassed reputation for speed, accuracy, and efficiency.

Complete details on this equipment and on rental of time and equipment at The Computation Center in Princeton, New Jersey will be forwarded on request. Write Dept. CE-1, Electronic Associates, Inc., Long Branch, N. J.

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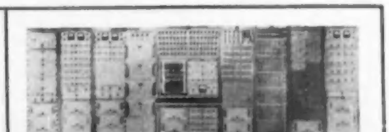

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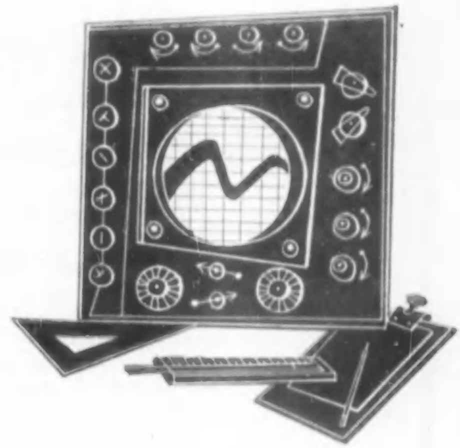


Control Stacks Up Mighty High Ahead

Launching makers and users into a promising new year are two rather incredible—but well validated—figures on the immediate and future potential for automatic control, just released by McGraw-Hill's Department of Economics:

- An overall plan by manufacturing industry to spend **30%** more for new plant and equipment in 1956 than it did in 1955—that's close to an increase of $3 billion.
- A projected five-year advance by all industry from a current $385 billion gross national product to $440 billion in 1960—a growth in which the control field will lead all others by **50%**.

It even amazed the case-hardened economists

The McGraw-Hill annual estimates on capital spending plans, based on a questionnaire mailed to a cross-section of business and industry people early each fall, long have been considered one of the most accurate indicators of the business outlook. But results of the last survey astonished even the economists who made it: huge upsurges on top of a record $29.4 billion spending in '55—almost as great as industry's expansion in 1951, when the Korean War began.

Specific plans by certain manufacturing groups are eye-poppers. Iron and steel firms top the list with a prospective increase in spending of 72%—from $865 million in '55 to $1,488 million in the coming year. Auto makers also plan a giant buying spree. Their expenditures last year—$1.1 billion—are dwarfed by an expected $1.9 billion in '56. The non-ferrous metal makers will run third with a 54% boost in new plant and equipment ($173 million more than in the past year).

Will control be all sold out?

Other traditionally large users of control also will have many more dollars to spend. Samples: chemical—up 34% to $1,383 million; paper—up 30% to $640 million; transport equipment (largely aircraft)—up 14% to $319 million; oil refining—up 14% to $825 million. Gains in others will be more modest: textiles—10%; machinery—7%; ceramics—7%; food—5%.

A paradox is revealed in the plans of certain other industries. In this group were the instrument and control makers—*and they report a planned increase in new plant in 1956 of only 2%.* Yet we are told that control production was stretched

FORD INSTRUMENT

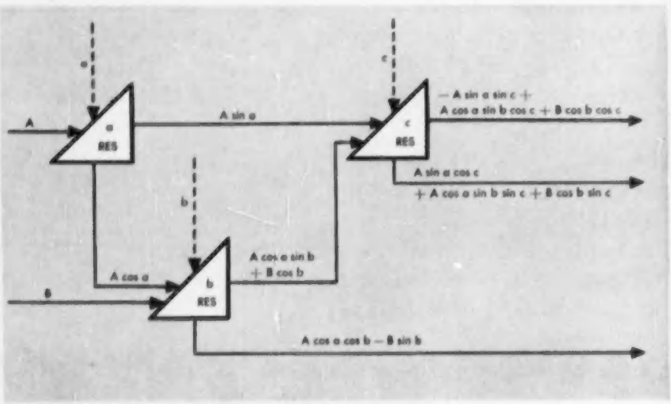
solved one design problem by

CASCADING RESOLVERS WITHOUT ISOLATION AMPLIFIERS

To get around a problem that arises in almost every resolver application Ford engineers recently designed a computer which, among other things, employed a chain of cascaded resolvers to solve complex trigonometric equations, without the use of isolation amplifiers. They solved such an equation as:

$$A \sin a \cos c + A \cos a \sin b \sin c + B \cos b \sin c$$

This was successfully done, without use of vacuum tubes or amplifiers in this circuit:



In view of the widespread use of resolvers to generate sine and cosine functions in modern electro-mechanical analogue computers, it is of great practical significance. Resolvers produced by the Ford Instrument Company have now reached such a high degree of precision, that it is possible to obtain, from an unloaded resolver (which accommodates a single angular quantity only), an accuracy to within less than one tenth of one percent. But most computing circuits call for the use of several resolvers, and once an ordinary resolver is loaded by another resolver, no matter how high its precision, the overall accuracy of the resolver cascade is seriously affected.

The conventional method of avoiding this difficulty is to use an isolation amplifier for each resolver, so that the resolver continues to operate under no-load conditions regardless of the size of the cascade. The importance of cascading without amplifiers is readily appreciated if we realize that the isolation amplifier usually increases the cost of the equipment, more than doubles the size and generates many times more heat that must be dissipated to prevent breakdown of the components. Furthermore, the use of vacuum-tube amplifiers always raises the problem of tube ruggedness and reliability, and requires an additional source of d-c plate voltage.

Have you problems which the engineers at Ford might solve by designing and manufacturing computers, controls or their elements? Write for further information.

85

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Division of Sperry Rand Corporation

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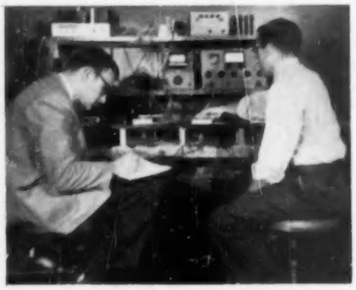
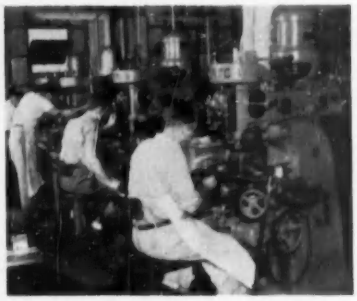
Ford's capabilities are among the finest in the country



One of the Ford laboratories where a particular design project has called for careful study of resolvers and resolver cascading. Two of the engineers assigned to this project are here checking results. From this work will come one of the new, highly classified weapon systems for the armed forces.



For accuracy and reliability—both vitally necessary in military instruments—experienced machinists must work to fine precision—in the order of .0005 of an inch. Here in one section of the shops of Ford Instrument Company, men are milling parts for an airborne computer.

During the past year Ford Instrument Company has been busy working on many contracts for the U. S. Air Force and the U. S. Navy Bureau of Aeronautics, designing and manufacturing complex computers, controls and their components. For over forty years, Ford Instrument Company has devoted most of its efforts in working for the government to the many problems of weapon controls.

taut last year. How will they keep abreast of the new demands?

Inherent in the McGraw-Hill outlook for the U.S. economy in the next five years is a warning to control manufacturers that they will have to shuck aside conservatism if they want to stay ahead of industry. And stay ahead they must . . . if they are to fulfill an estimated increase in unit sales of 50% by 1960. Not far behind control in the estimates of growth in the next five years are the chemical field (40%), electrical power generating equipment (40%), and atomic energy (which is reckoned at 35%, but which may zoom with new developments).

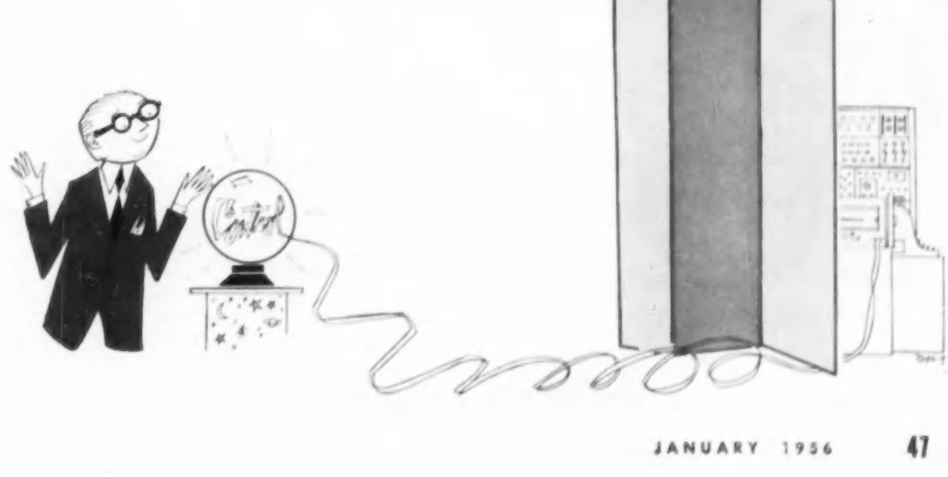
Other industries that are expected to show above-average (20-25%) growth: petroleum, appliances, construction, metalworking. Average growth (15%) will be shown by the trucking and mining industries. And below average growth will occur in food, textiles, and aircraft manufacture.

Only one major market for control is expected to decline in the next decade: defense. This market, now involving $41 billion for developments and product, is expected to drop to $36 billion in 1960, $30 billion by 1965. But, the economists hasten to add, these figures are likely to rise dramatically with any crisis.

Conclusions that can be drawn from the two surveys can bolster and guide the control engineer in the days ahead. For one thing, he can still count on sizable control activity in such large continuous process industries as chemical and oil, where the outlay for automatic control often approaches 20% of new plant spending. And he can look for almost proportionate gain in emphasis on using control by the other industries as they strive to continuize or "automatize" their operations.

But the fact that he can count on the most—whether he designs control, or puts it to work in the field—is that he'll be rather busy for the next few years. So busy, in fact, that he may have to work 70 hours a week to help bring in the 35-hour work week that industry seems to be headed for.

**As control grows—
so grows the nation**



Control
ENGINEERING
JANUARY 1956

Interchange Fortifies Control

The interchange of control system technology and equipment between military and industry has widened and fortified the base of practice throughout the entire control field. Although the movement has been catalyzed by publication and education, its main spearhead has been the mobility of the control engineer himself.

Today the shuttle of ideas and hardware is predominantly from military to industry. Components such as the electro-hydraulic power control valve, entire sets of mathematical tools for analysis and synthesis, and complete systems of information handling have made the switch. The drift of engineers is less one-sided. A recent questionnaire to a cross-section of our readers roughed-in the dimensions. Of the respondents, one-quarter do solely military control work, two-fifths solely industrial control, and one-third both. One eighth had changed from industry to military and one-eighth had moved the other way—a numerical draw but a healthy gain in the spreading of know-how. A whopping majority (three-quarters) of those in military control foresaw an industrial future for their work. They ranked machine control applications first and process control second.

The flow of control people, product, and principles was not always greater to industry. At the start of World War II, designers of ordnance and guidance systems drew heavily on industrial sources. From the steel mill they borrowed the amplidyne generator and the hydraulic positioner. The thyratron came from the resistance welder, the selsyn from synchronizing applications at the Panama Canal, and the highly sensitive pneumatic transmitter and controller from petroleum refining. Each interchange increased our margin of safety in armament. Each will fortify our industrial productivity today.

THE EDITORS

Through dynamic analysis the control engineer strives to optimize control performance and cost. To perform this analysis he must know the dynamic characteristics of each separable part of the complete system. Articles by Reswick (Vol. 2, No. 6) and Reynolds (Vol. 2, No. 10) described how to extract these characteristics from responses to sinusoidal and random disturbances. This article, first in a group prepared by CONTROL ENGINEERING editors from a forthcoming book by Taylor Instrument authors, briefly shows how to derive dynamic characteristics of existing plants by extracting from response to known experimental step disturbance. It then presents a method for calculating the characteristics of a plant that may be in the design stage and works out three plant examples using the method. Subsequent articles will complete the integration of process, transmission elements, and controller into a complete automatic system.

How to Reckon Basic Process Dynamics

LESLIE M. ZOSS, Taylor Instrument Cos.

Process control improvement requires an adequate knowledge of the dynamic and static characteristics of the system to be controlled. Dynamic characteristics consist mainly of combinations of transfer lags and distance velocity lags. Often in a system study, these characteristics are assumed. How can their actual magnitudes be found?

Two possible approaches are:

EXPERIMENTAL—in which the process characteristics are determined directly from the reaction curves that the process variable follows in response to a measurable disturbance, such as a sustained control valve movement. Obviously, this method only applies to existing processes. It is used a great deal in trouble-shooting.

ANALYTICAL—in which the dynamic characteristics derive from equations representing energy or mass balance. This method can be applied to an existing process as well as to one that is in the design stage.

THE EXPERIMENTAL METHOD

Time constants can be extracted from step response data by the *per cent incomplete response* technique shown here. This technique involves the evaluation of *linear transfer lags*.

Single Linear Transfer Lag

The response to a step change disturbance of a single linear lag is shown by the solid line of Figure 1. Here, at any time *t*, the curve designates the *per cent complete* response. Then the per cent incomplete response, *b*, is found by subtracting a from 100 per cent, and *b* equals *100-a*. Since the time constant equals the time of 63.2 per cent of the *complete* response, it also equals the time of 36.8 per cent of the *incomplete* response.

If this per cent incomplete curve is plotted on a logarithmic scale and *time* on a linear scale, a straight line (Figure 2) results. As in Figure 1, the coordinates are non-dimensional so that the information will not be restricted to the actual magnitude of the time constants under consideration. Figure 2 shows that the time constant equals the time of 36.8 per cent *incomplete* response (36.8 per cent at *1T*).

Two Series-Connected Linear Lags

Suppose that step response data have been obtained through an experimental run on a different

RESPONSE CURVES YIELD LAG MAGNITUDES

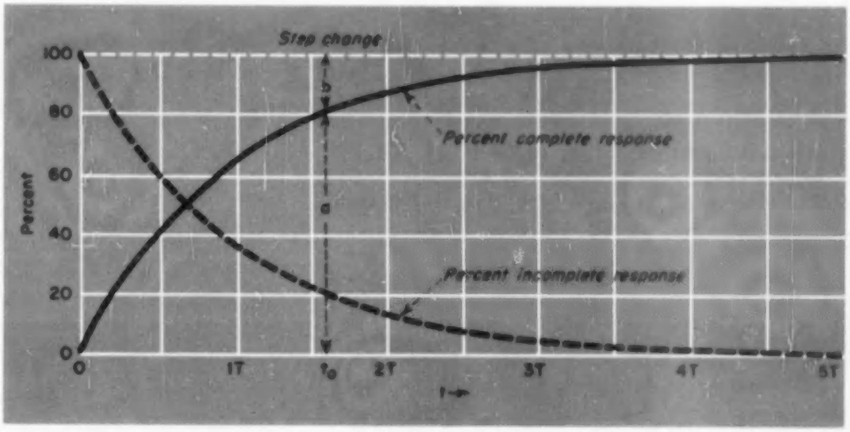


FIG. 1. The solid line represents the reaction curve of a single linear lag process. The reaction curve is also called the per cent complete response, and at time "t" it equals "a" per cent complete. The per cent incomplete response, the dashed line, is the difference between 100 per cent and the per cent complete, or b equals 100-a per cent. The time constant, T, of the process equals the time for 36.8 per cent incomplete response.

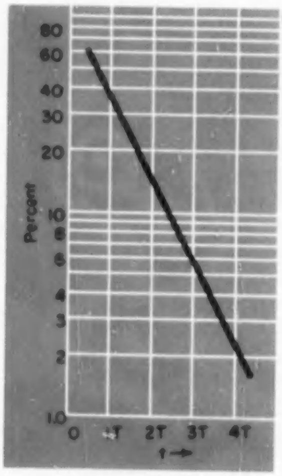
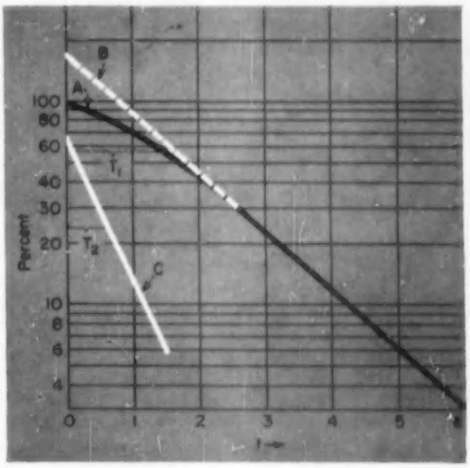


FIG. 2. Here, the per cent incomplete response characteristic has been replotted on a logarithmic scale for magnitude against a linear time scale. The advantage of this new plot is a straight line for the reaction.

FIG. 3. In this graph, the per cent incomplete response (Curve A) for two series-connected linear lags has been plotted directly on semi-logarithmic paper. The straight-line portion of Curve A extends back to the zero time axis, giving Curve B. The larger of the two time constants can then be obtained from Curve B. The difference between Curves A and B is plotted as Curve C, from which is computed the second time constant. See the text for the exact procedure in computing the time constants.



system. Then, it may be possible to determine whether this system can be represented, with reasonable accuracy, by two time constants. If these time constants are not nearly equal, they can be found by the per cent incomplete response method.

Curve A of Figure 3 represents the per cent incomplete response for a typical two-series connected linear lag system. If accurate data are obtained for large values of time, the linear portion of this curve is extended straight back to the zero time ordinate, developing Curve *B*. To determine the larger time constant T_1, read the vertical intercept of Curve *B*, 1.67, and take 36.8 per cent of this value, which equals 61.5 per cent. The time constant T_1, is equal to the time when Curve *B* has an ordinate of 61.5 per cent. Thus, in this case T_1 is 1.5 min. So far, this method is similar to that for finding the time constant of a single linear lag, described above.

Now to find the value of the second time constant, T_2, plot Curve C, the difference in values between Curve *B* and Curve A. (If these differences do not plot as a straight line, the system cannot be represented as two series-connected lags.) Curve C intercepts the zero time ordinate at 0.67, and 36.8 per cent of 0.67 equals 24.6 per cent. Then, the time constant T_2 equals the time when Curve C has an ordinate of 24.6 per cent, which is 0.6 min.

It is theoretically possible but not practical to repeat this procedure with more time constants.

THE ANALYTICAL METHOD

The analytical method determines processes characteristics by calculation. For instance, physical

constants and the geometry of a temperature-controlled process establish the parameters for a heat balance. This heat balance, a transient condition, gives time constants as *direct* answers.

The rate of heat flow in equals the sum of the rate of outward heat flow and the rate of heat flow into thermal storage. Thus, in a heat balance, the basic equation is:

$$Q_{in} = Q_{out} + Q_{storage}$$

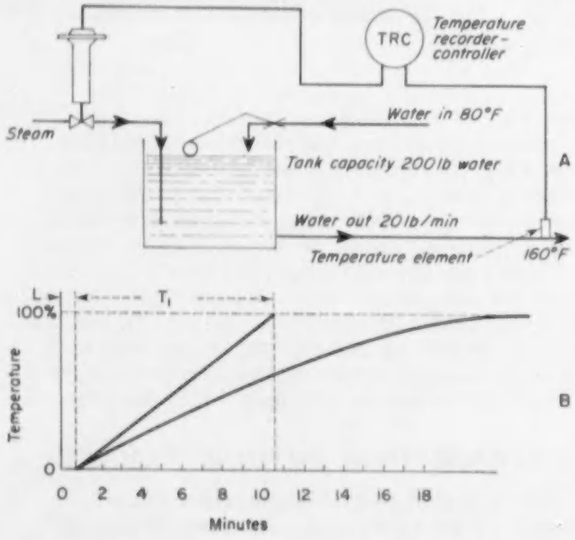
where Q equals the rate of heat flow in Btu/min.

PROCESS I: TEMPERATURE CONTROL —SINGLE LINEAR LAG

Figure 4 illustrates a typical system having a single linear lag plus distance velocity lag. A sudden and sustained pressure change at the steam valve operator will cause the process to unbalance and seek a new balance at a different final temperature. Just how the process reacts is shown in Figure 4B. The distance velocity lag (L), as read from this curve, is 0.6 min. The time constant T_1, or 63 per cent response time, is about 10 min. Thus, the values of the desired characteristics have been found.

But suppose the system was in the design stage. The procedure then is somewhat different, for physical constants of the system must be known to determine analytically the characteristics of the process. Thus, for Figure 4A, the following are known:

FIG. 4. A temperature control process, which has one time constant and a distance velocity lag, is shown in Figure 4A. From its reaction curve, Figure 4B, the value of the distance velocity lag and the single time constant may be obtained. These same results can be computed on an analytical basis from the data in Figure 4A.



water in tank........................200 lb
water in line between tank and bulb 12 lb
water flow ....20 lb/min
steam flow (maximum)...........6 lb/min
incoming water temperature........80 deg F
outlet water temperature..........160 deg F

Distance Velocity Lag

The distance velocity lag is the time it takes the temperature element to sense a change in temperature in the tank. Therefore, for the system above, the distance velocity lag (L) equals

$$\frac{12 \text{ lb}}{20 \text{ lb/min}} = 0.6 \text{ min.}$$

Time Constant

To determine the time constant of this process go back to our basic balance equation:

$$Q_{in} = Q_{out} + Q_{storage} \quad (1)$$

where Q is the rate of heat or energy flow.

For a 3-15 psi stroke of the steam valve the steam flow change is 6 lb/min, or $\frac{1}{2}$ lb/min/psi if the valve is assumed to be linear. Now, a change of m psi at the steam valve operator results in a rate of energy *added* to the system:

$$Q_{in} = 1/2 \text{ lb/min/psi} \times m \text{ psi} \times 1000 \text{ Btu/lb} = 500\, m \text{ Btu/min} \quad (2)$$

where 1000 Btu/lb is the latent heat of the steam.

The rate of energy *leaving* the system may be found as follows:

$$Q_{out} = 20 \text{ lb/min} \times 1 \left(\frac{\text{Btu}}{\text{lb °F}}\right) \times (\theta_1 - 160) \text{ °F} \quad (3)$$

where θ_1 = final temperature in °F of tank 1, and $1 \frac{\text{Btu}}{\text{lb °F}}$ is the specific heat of water.

Under equilibrium conditions the water in the system and the water leaving the tank is at 160 F. Thus, the final tank temperature after a change of m psi is θ_1 equals $(160 + \theta)$ deg F, where θ is the temperature change resulting from the addition of steam. With this change in variable, Equation 3 can be rewritten as

$$Q_{out} = 20 \text{ lb/min} \times 1 \left(\frac{\text{Btu}}{\text{lb °F}}\right) \times \theta \text{ °F} \quad (3a)$$

The rate of energy *stored*, assuming instantaneous mixing of the feed water, is

$$Q_{storage} = 200 \text{ lb} \times 1 \left(\frac{\text{Btu}}{\text{lb °F}}\right) \times \frac{d\theta_o}{dt} \frac{\text{°F}}{\text{min}} \quad (4)$$

The derivative of θ_1 with respect to time results in $d\theta/dt$, since

$$\frac{d\,\theta_o}{dt} = \frac{d\,(160 + \theta)}{dt} = \frac{d\,(160)}{dt} + \frac{d\,(\theta)}{dt} = 0 + \frac{d\,\theta}{dt}$$

Equation 4 may now be written as

$$Q_{storage} = 200\ p\theta \quad (4a)$$

where $p = d/dt$, the Heaviside operator.

Substituting Equations 2, 3a, and 4a into Equation 1,

$$500m = 20\theta + 200p\theta, \text{ or}$$

$$\frac{\theta}{m} = \frac{25}{(1 + 10\ p)} \quad (5)$$

Equation 5 is a linear first order differential equation with constant coefficients. From the term $(1 + 10p)$ we see that the time constant T_1 equals 10 min. Thus, the analytical method verifies the values of L and T_1 obtained from the reaction curve.

PROCESS II: TEMPERATURE CONTROL —DOUBLE LINEAR LAG

Adding another tank to the previous system complicates the process. Figure 5 shows this new system and its reaction curve. Here, the distance velocity lag has been eliminated by placing the temperature sensing element in the second link. The S-shaped reaction curve indicates the process has more than one time lag.

The time constants can be determined from the reaction curve by the incomplete response method. Evaluation by this procedure will show that the system can, indeed, be expressed by two time constants. These values are *T_1 equals 10 min*, and *T_2 equals 5 min*.

Now, if it assumed that this process is in the design stage, then the information shown in Figure 5 aids in finding the time constants. Note that the conditions of the first tank of this system are the same as those in the first example.

The transient energy balance of the system is given by:

$$Q_{in}\ (\text{Tank 1}) = Q_{out}\ (\text{Tank 1}) + Q_{storage}\ (\text{Tank 1}) \text{ and} \quad (6)$$

$$Q_{in}\ (\text{Tank 2}) = Q_{out}\ (\text{Tank 2}) + Q_{storage}\ (\text{Tank 2}) \quad (7)$$

Note that Q_{out} (Tank 1) = Q_{in} (Tank 2).

The rate of energy *leaving* tank 2 is

$$Q_{out}\ (\text{Tank 2}) = 20\ \frac{\text{lb}}{\text{min}} \times 1\ \frac{\text{Btu}}{\text{lb F}}\ (\theta')\ ^\circ\text{F} \quad (8)$$

where θ' = temperature change of tank 2 in deg F,
or $\theta' = (\theta_2 - 160)$ F.

The rate of energy *stored* in tank 2 is:

$$Q_{storage}\ (\text{Tank 2}) = 100\ \text{lb} \times 1\ \frac{\text{Btu}}{\text{lb}} \times \frac{d\theta'}{dt}\ \frac{^\circ\text{F}}{\text{min}}$$

$$\text{or } Q_{storage}\ (\text{Tank 2}) = 100\ p\ \theta' \quad (9)$$

Substituting Equations 3, 8, and 9 in equation 7 gives,

$$20\ \theta = 20\ \theta' + 100\ p\ \theta' \text{ or}$$
$$\theta = \theta' + 5\ p\ \theta = \theta'\ (1 + 5\ p) \quad (10)$$

Now, from Equation 5

$$\theta = \frac{25\ m}{(1 + 10\ p)}, \text{ so that Equation 10 becomes}$$

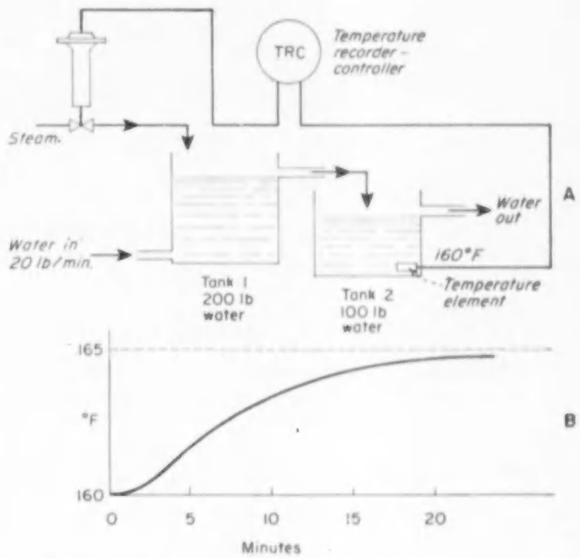


FIG. 5. Figure 5A shows another temperature control process, but this one has two tanks that create two time constants. The typical S-shaped reaction curve, Figure 5B, tells that there is more than one time constant. Like the data in Figure 4A, that in Figure 5A may be used to compute the values of the two time constants.

$$\theta'\ (1 + 5\ p) = \frac{25\ m}{(1 + 10\ p)} \text{ or}$$

$$\frac{\theta'}{m} = \frac{25}{(1 + 10\ p)\ (1 + 5\ p)} \quad (11)$$

From this result the time constants are obtained; namely T_1 equals 10 min and T_2 equals 5 min. These values confirm those obtained from evaluation of the reaction curve in Figure 5B.

PROCESS III: PRESSURE CONTROL —SINGLE LINEAR LAG

The control of pressure is an interesting illustration of another example of the procedure for finding process characteristics. Proper analysis of the system in Figure 6 requires that the load effects be taken into account.

To do this we must have the static curves of tank pressure, P_t, versus air flow, Q, out of the tank for various load pressures P_L. Curves of this type, assuming linear conditions, are shown in Figure 7. Although these curves probably would not be obtained in an actual system, the assumption of small changes around any chosen operating point upholds the linearity requirements. However, if the operating point is unknown then the limiting conditions of the process operation, in this case the load resistance, must be considered. From the slopes of the load pressure curves of Figure 7, note that the load resistance varies between the limits of 5 psi/lb/min (for

load pressure curve P_{L1}) to infinity when Q equals zero. The variations must be considered in the analysis.

For transient mass balance conditions

$$Q_{in} = Q_{out} + Q_{storage}$$

where Q = air flow, lb/min. (12)

A sudden change of m psi at the valve operator creates a step change at the input of the system. Since a 12 psi change at the valve input causes the load flow to go from 0 to 10 lb/min, the relationship becomes

$$Q_{in} = 0.83 \frac{\text{lb/min}}{\text{psi}} \times m \text{ psi} \qquad (13)$$

Now, if it is assumed that the operating point lies on P_{L1} and that the tank equilibrium pressure is 50 psi, then the following obtains:

$$Q_{out} = \frac{10 \text{ lb/min}}{50 \text{ psi}} (P_t - 50) \text{ psi} = \frac{Po}{5} \frac{\text{lb}}{\text{min}} \qquad (14)$$

where P_t = total tank pressure, and
P_o = change in tank pressure.

The rate of change of air stored in the tank becomes

$$Q_{storage} = \rho \frac{V}{P^*} \frac{dP_t}{dt}, \text{ or}$$

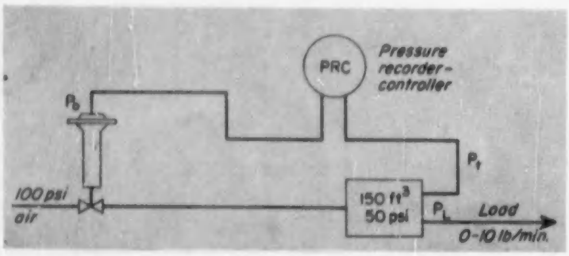


FIG. 6. The pressure control system above represents another single linear log process. But here the load pressure, P_L affects the value of the time constant, which depends on the operating point, as shown in Figure 7.

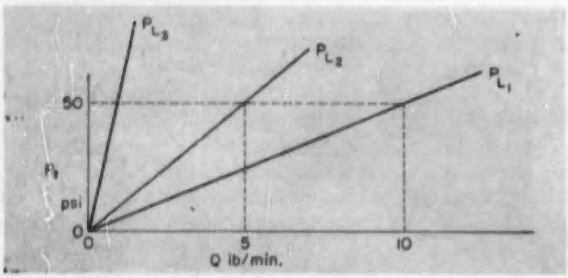


FIG. 7. For a given tank pressure, P_t, the air flow, Q, out of the tank depends on the value of the load pressure, P_L. Therefore, dynamic analysis of the system in Figure 6 requires that the operating point be fairly constant or that the worst possible condition be used in computing the necessary controller characteristics.

$$Q_{storage} = \rho \frac{V}{P^*} \frac{d(P_o + 50)}{dt} = \rho \frac{V}{P^*} \frac{dP_o}{dt}$$

Again, the operational form of the derivative simplifies the calculations, so that $Q_{storage} = \rho \dfrac{V}{P^*} p P_o$ (15)

where ρ = specific weight of air, 0.076 lb/ft³
V = tank volume, 150 ft³
P^* = atmospheric pressure, 14.7 psi.

Thus

$$Q_{storage} = 0.77 \, p \, P_o \qquad (15a)$$

Substituting Equations 13, 14 and 14a in Equation 12 yields

$$0.83 \, m = \frac{P_o}{5} + 0.77 \, p \, P_o \qquad (16)$$

Equation 16 reduces to the familiar form for a transfer function

$$\frac{P_o}{m} = \frac{4.15}{1 + 3.85 \, p} \qquad (17)$$

from which it is seen that the time constant equals 3.85 min. When p, the frequency dependent term, is zero then the zero frequency gain equals 4.15. This gives one limit of our process operation.

But, if the above procedure is carried out for a different operating point, say P_{L2}, then the resulting transfer function is

$$\frac{P_o}{m} = \frac{8.3}{1 + 7.7 \, p} \qquad (18)$$

Here, the time constant equals 7.7 min and the zero frequency gain is 8.3.

Equations 17 and 18 show the generalized form of the transfer function for this process to be:

$$\frac{\text{output}}{\text{input}} = \frac{K \, T}{1 + T \, p} = \frac{K}{1/T + p}$$

where K equals 1.08 for this particular system.

In the extreme situation, when load resistance goes to infinity, T also approaches infinity and the transfer function becomes K/p. This is the other limit of the process operation.

A frequency response plot of the above pressure process leads to some interesting conclusions. But before reaching these conclusions, it is necessary to assume some reasonable values of time constants and zero frequency gains for the valve and measuring circuit. For the valve the time constant is 0.15 min and the zero frequency gain is unity. For the measuring circuit transmitter the time constant is 0.10 min. And its zero frequency gain is 0.12, because the output varies 12 psi for 100 psi input.

Figure 8, the frequency response plot, describes the characteristics for the individual components. Dashed lines represent the control valve, measuring circuit, and three different values of T for the process; and solid lines the overall response of the complete system. The phase shift diagram shows that the system phase lags blend at some frequency less than 1 cpm, regardless of the time constant of the process.

Now, an acceptable phase margin of 30 deg

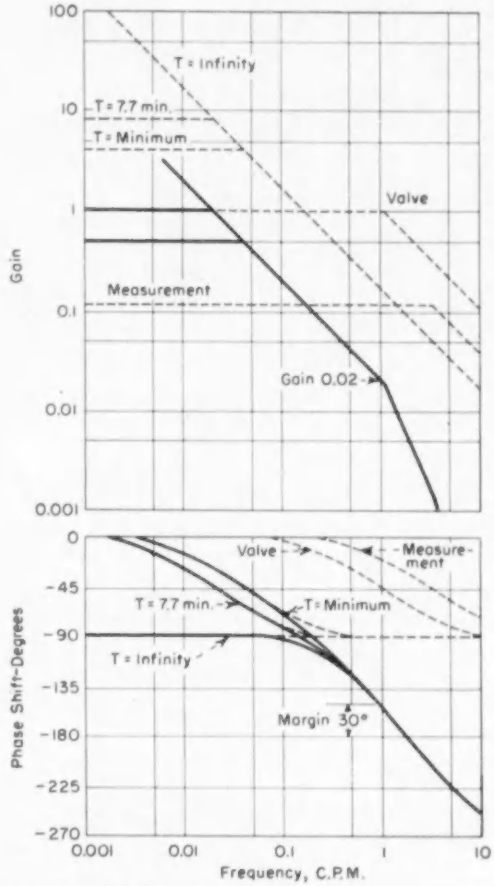


FIG. 8. This frequency response plot for the system of Figure 6 shows that the overall system gain, for stable operation of the process, is the same regardless of the particular operating point (and hence time constant) of the tank.

occurs at about 1 cpm, and at this frequency the overall process gain is 0.02. Thus, a controller gain of 1/0.02, or 50, assures stability of the system. This controller gain results in a fixed value regardless of the size of the process time constant. But some economic benefit may accrue if the system can be designed for a smaller tank. What, then, are the controller requirements and their effect on the overall system?

Suppose that the tank volume has been cut to a point where its time constant is reduced by a factor of ten, as compared with the original system. The corresponding frequencies thus increase by the same factor of ten. The characteristics of the control valve and measuring circuit remain as before. Figure 9 shows the frequency response of the overall system.

Here the 30 deg phase margin occurs at frequencies dependent on the particular time constant of the process; and thus the corresponding process gains differ. Now, the product of process and controller gains should not exceed unity for a stable system. The highest value of process gain, 0.2, occurs at infinite *T*, and this should be used in calculating the controller gain. Therefore, controller gain equals 1/0.2 equals five.

Thus, by reducing tank size the allowable controller gain has been decreased by a factor of ten. This situation could create a difficulty in that excessive offset error may occur following load changes. Therefore, an additional controller mode, say reset, might be necessary to compensate for this offset.

The plant examples used above are based on *Process Lags in Automatic-Control Circuits*, J. G. Ziegler and N. B. Nichols, Trans. ASME, Vol. 65, 1943.

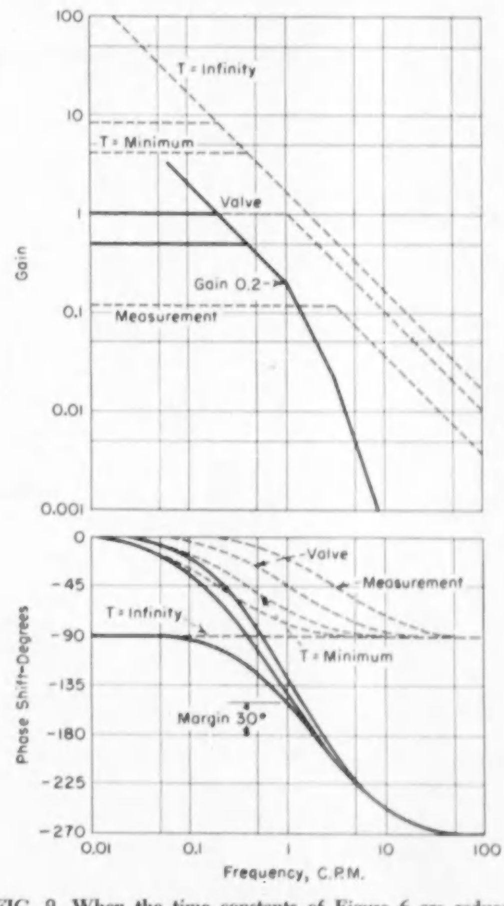


FIG. 9. When the time constants of Figure 6 are reduced by a factor of ten, the frequency range for the tank response increases by the same factor. But now the overall phase shift curves differ at the phase margin frequencies. Therefore the process gain—and the controller gain—differ for each value of the process time constant. Thus, the conservative (highest) value of process gain, equal to 0.2, assures stable operation regardless of the operating point.

Four Steps to Practical Machine Tool Control

1. ANALYZE OPERATIONS

2. GROUP FUNCTIONS

3. LAY OUT CIRCUIT

4. ADD MANUAL CONTROL

T. C. CAMERON, Sundstrand Machine Tool Co.

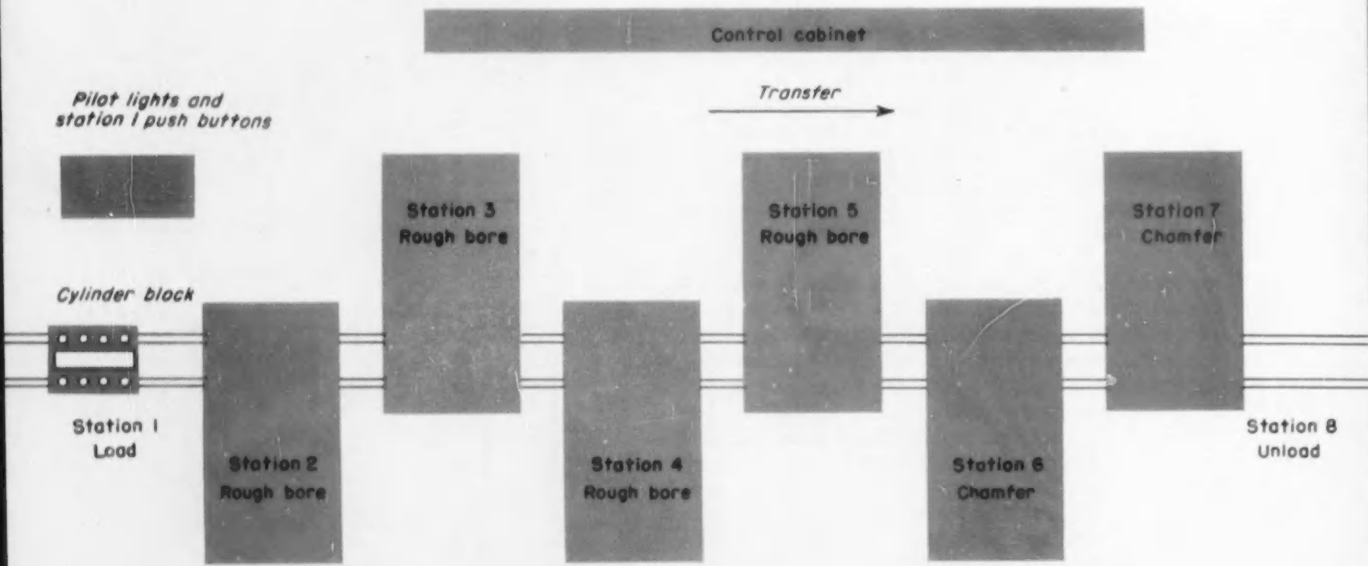


FIG. 1. Schematic diagram of six-head transfer machine shown in Figure 2.

FIG. 2. Rough boring unit of an automatic line for engine blocks.

THE GIST: The majority of machine tool operations can be done most cheaply with straight-line motion at constant feed rates. This indicates magnetic control, limit switches, and squirrel cage motors, combined to form a system that will cause the machine to go through its functions in the proper sequence.

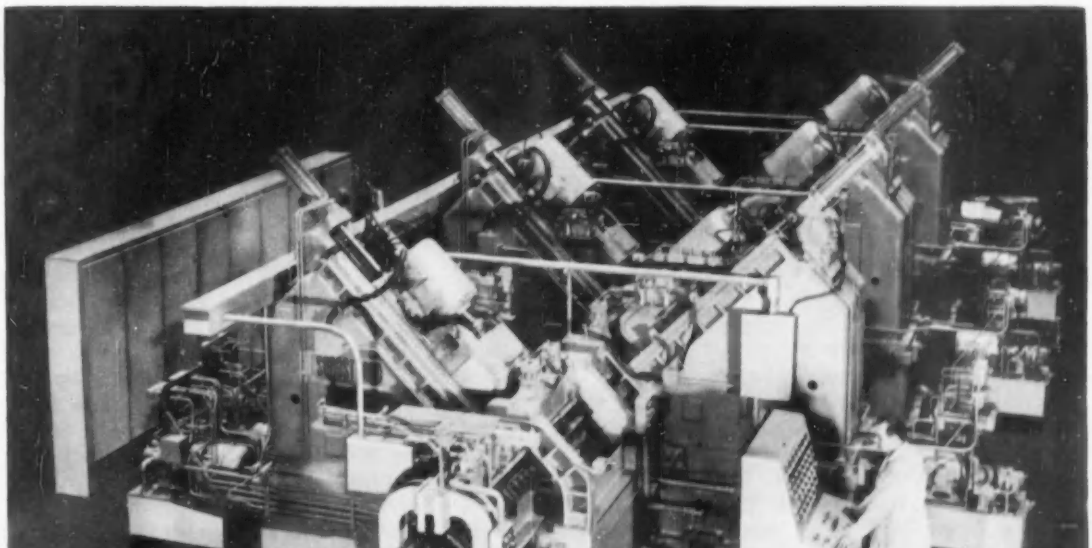
The design of this type of system can be simplified by a logical series of steps that applies, with minor variations, to any sequential control. In the first step, machine operation is analyzed and a cycle diagram set up for the entire machine. The overall machine functions are organized in step two into logical groups of control circuits. In step three the individual group control circuits and interlocks between groups are designed. And finally, the control system is modified to permit manual control. With the transfer machine in Figure 2 as an example, this article tells how to apply this technique.

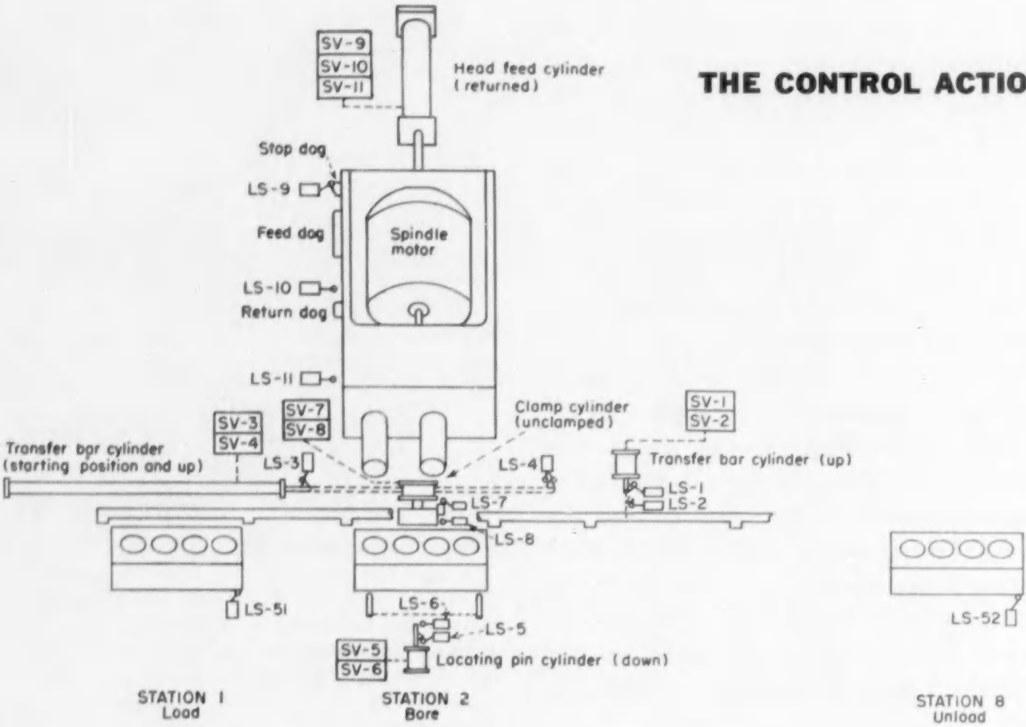
Figure 1 shows schematically the cylinder block line pictured in Figure 2. This integral group automatically machines, transfers, and loads and unloads when conditions permit. The cylinders are rough-bored two at a time in four stations, and chamfered in the last two stations.

The control system performs three basic functions: control of the moving elements; indication of position of the machine elements; and protection of the machine, the operating personnel, and the control itself. Since a production line may be several hundred feet long and may have only a few operators, machine operation and safety depend exclusively on control. Easy maintenance is important, since there are hundreds of possible points for trouble and "down time" is expensive. Thus control circuits should be as simple and direct as possible and local indicator lights should be used liberally.

1. ANALYZE MACHINE OPERATIONS

The first requirement is thorough familiarity with the machine itself and the conditions under which it will be operated. Determine the sequence of all movements necessary to complete a cycle. Which ones can or must be operated independently, and which can be grouped to operate as a unit? The necessary push buttons and indicator lights can be approximated and all driving means noted. This in-





THE CONTROL ACTION . . .

cludes the motions controlled by hydraulic solenoid valves.

Figure 3 shows stations 1, 2, and 8 and the transferring mechanism. The transfer bar extends the full length of the machine to simultaneously transfer all parts to the next station.

The mechanical cycle is as follows:

a. transfer bar lowers to engage work
b. transfer bar advances, moving each part to the next station
c. locating pins in each fixture rise
d. clamps lower to secure part
e. transfer bar raises, then returns; simultaneously, all heads start rapid approach
f. heads feed individually
g. heads rapid return individually
h. locating pins drop and clamps rise
i. cycle repeats if new part is available and the finished one has been removed from the unload station.

The total machine cycle can be reduced to groups of motions. The transfer cycle is a group; down then forward is the first half and up then return the second half. Each fixture is a group, and each head another group. Each head must rapid approach, feed, and rapid return when its fixture is clamped.

A group of indicator lights for each station is convenient for showing the following: motors running, cycle on, cycle completed, fixture clamped, and fixture unclamped. Lights can also show the transfer bar position and the condition of the load and unload stations.

Limit Switches

An important part of the machine analysis is locating the limit switches for the particular cycle. A limit switch is required at each end of each motion, and at any other point where a machine member stops, changes rate, or starts another motion. The switches should be mounted so that their operation is not affected by motions other than the one they are to detect. Thus, every significant position of the machine can be detected and any physically possible sequence controlled. The limit switches convey machine information to the control, where it is stored until a particular group of motions is completed. Then the proper combination of relays starts the next motion in the sequence.

When the above information has been collected it is usually convenient to arrange it graphically in a cycle diagram or in a reference table. Figure 4 shows a cycle diagram for the whole machine. Figure 3 is a mechanical display of about the same information for station 2.

The solenoid valves are located on the cycle diagram alongside the motions that result when the solenoids are energized. The limit switches are placed to show the time they are operated during a particular motion. For example, station 2 head

. . . AND ITS CYCLE DIAGRAM

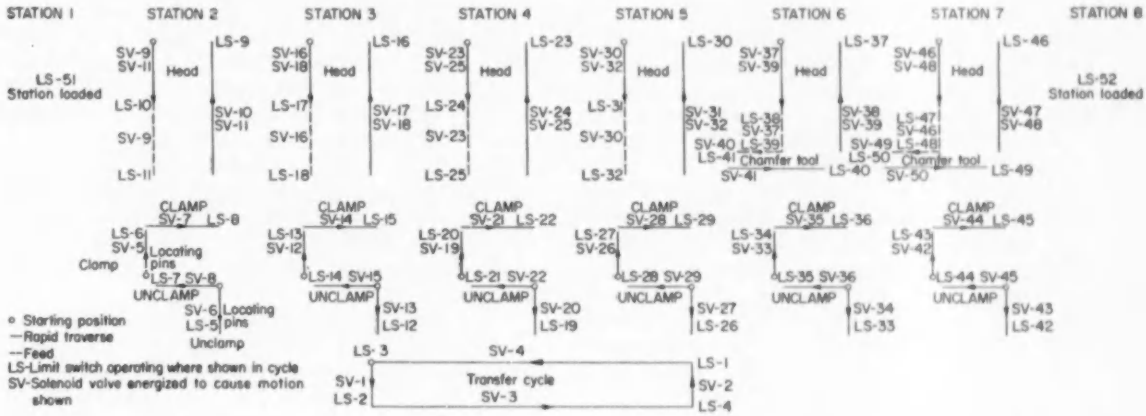


FIG. 3. Detailed schematic of stations 1, 2, and 8, showing all control components. Since other five work stations are similar, this represents the whole machine.

FIG. 4. Cycle diagram for entire machine. Shows all machine motions plus the control components that cause and are actuated by these motions.

rapid approaches when *SV-9* and *SV-11* are energized. Limit switch *LS-10* de-energizes *SV-11* and the head feeds to the end of the stroke. At this point, *LS-11* is actuated, energizing *SV-10* and *SV-11*. Then the head rapid returns to *LS-9*, which de-energizes *SV-10* and *SV-11* to stop the head.

To summarize the first step in the design procedure: collect all the information about the machine and coordinate it as shown in Figure 4.

2. GROUP MACHINE FUNCTIONS AND CONTROL CIRCUITS

The second step in designing a control system for a machine of the type under discussion is to determine the general arrangement of the control, Figure 5. Transferring, work handling, lubrication, chip conveyors, etc., are common to all working stations and make a convenient control group. In addition, each working station becomes a separate control group.

Next, each working station group must be interlocked with the common or transferring group. Thus interlocked, each working group requires from the common group a signal that transferring is complete before it can start a machining cycle. Also, when the cycle ends, a signal must be sent from every station before transferring can begin.

For example, at the end of the station 2 cycle (Figure 6B), *CR-11* is released and *CR-7* and *CR-9* are closed. *CR-11* and *CR-9* assist in latching *CR-5*, Figure 6A, and *CR-5* and *CR-7* must be closed to transfer. Then, at the end of the transfer stroke, *LS-4* energizes *CR-4*, Figure 6A. In Figure 6B a *CR-4* contact latches *CR-11* and releases *CR-12* to clamp and start the station 2 machining cycle.

Each group can then be built on a reasonably sized panel and can have a separate diagram that requires a minimum of reference to other panels. This simplifies the building and servicing of the equipment.

3. DESIGN DETAILED CIRCUIT

This third step consists of laying out a circuit with the appropriate relays for the desired automatic sequence. The following approach is based on complete electrical control.

Most of the relays and their functions can be determined before starting the circuit design. They can be divided into three categories: those that provide additional contacts (energized only by limit switches); those for starting and stopping (usually push-button-operated in a three-wire circuit), and those that are mechanically latched.

Three-Wire Control

Three-wire circuits for running motors and effecting cycles should be worked into a circuit first, in

conjunction with the proper overload and short circuit protection. "Safe failure" must also be provided.

Figures 6A and 6B show the common control group and the control for station 2. The other stations are identical to station 2 except that the chamfering stations have one additional motion. Thus Figure 6 covers the whole machine in principle. The circled number at the push buttons indicates the station where the button is mounted.

The motors are started and protected in groups; see *H1*, *H2* and *CR-A* in Figure 6A, and *S*, *H*, and *CR-E* in Figure 6B. The fixture motors must be started first to provide clamping (if required). Then other motions can start. Relay *CR-A*, energized when the fixture and transfer motors are running, has a contact in each station to indicate this condition. A single master stop button stops the whole machine; so does the failure of a fixture motor. Wedge type clamps sustain clamping pressure, even if a fixture motor stops in the clamped position.

If *CR-A* is energized, and the "control" selector switch is on *Automatic*, *CR-G* is energized and the station 2 motors can be started from either station 1 or station 2. If it is on *manual*, the motors can be started from station 2 only. Thus station 2 can run without the danger of the motors starting unexpectedly from station 1. The station 2 motors can be stopped by the push button or the overload relays without affecting the other stations. If this happens during an automatic cycle, the other stations continue to the end of their cycles. But then the machine will not transfer, since one station hasn't completed its cycle.

CR-B and *CR-F* are cycle control three-wire relays. Relay *CR-B*, in Figure 6A, allows the transfer bar to be stopped at any time but re-started only if the other machine conditions are satisfactory. The transfer solenoid valves, *SV-1*, 2, 3 and *SV-4*, are energized by a *CR-B* contact, thus permitting *CR-B* to override the automatic control of the bar.

CR-F is the cycle relay for station 2, Figure 6B. If this relay is in its normal energized position, station 2 cycles automatically when it is loaded with a new part. Then, with *CR-F* energized and de-energized by cycle start and stop buttons, the motors and spindle can run while the cycle is stopped and restarted. Also, each station can start individually after a new part has been loaded into the fixture. This flexibility is not required in normal daily operation, but is a convenient feature during "down time".

The master cycle-start and cycle-stop buttons energize relays *CR-C* and *CR-D*, Figure 6A, to control all cycles simultaneously by contacts in each station.

In normal operation, all cycle relays—*CR-B*, *CR-F*, and their counterparts in the other stations—remain energized after starting. Then, whenever all the cycles are finished, the unload station is empty, and the load station is full, the cycle repeats automatically. The above three-wire controls are the framework into which the sequencing control is fitted.

Latching Relays

Latching relays are used to determine the direction of moving elements and as "memory" devices. For example, a head may run through a cycle and return, leaving all machine elements in the same place they were when the cycle started. A relay latched or released at the end of the cutting stroke is one way of indicating the head has run. And in the case of power failure or machine stoppage, latching relays can "remember" what has run previously and their direction of motion when stopped.

Relays can control machine functions singly or

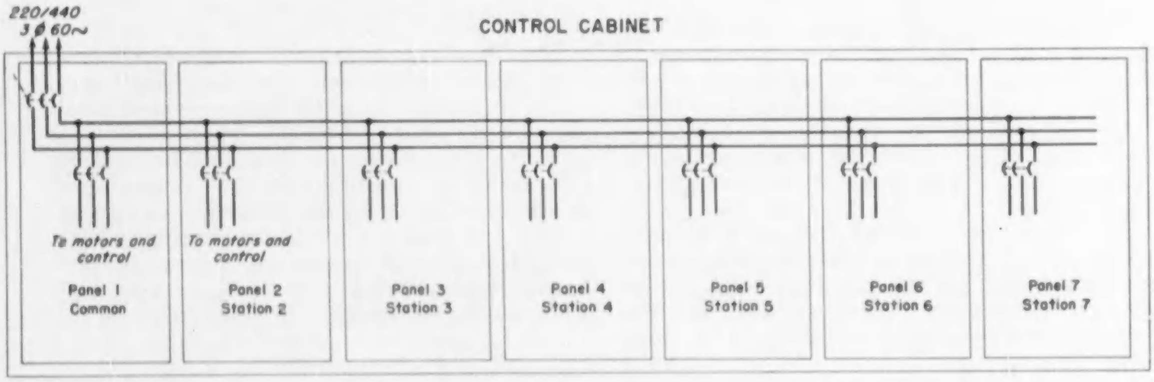


FIG. 5. Typical control cabinet arrangement for multi-station transfer machine.

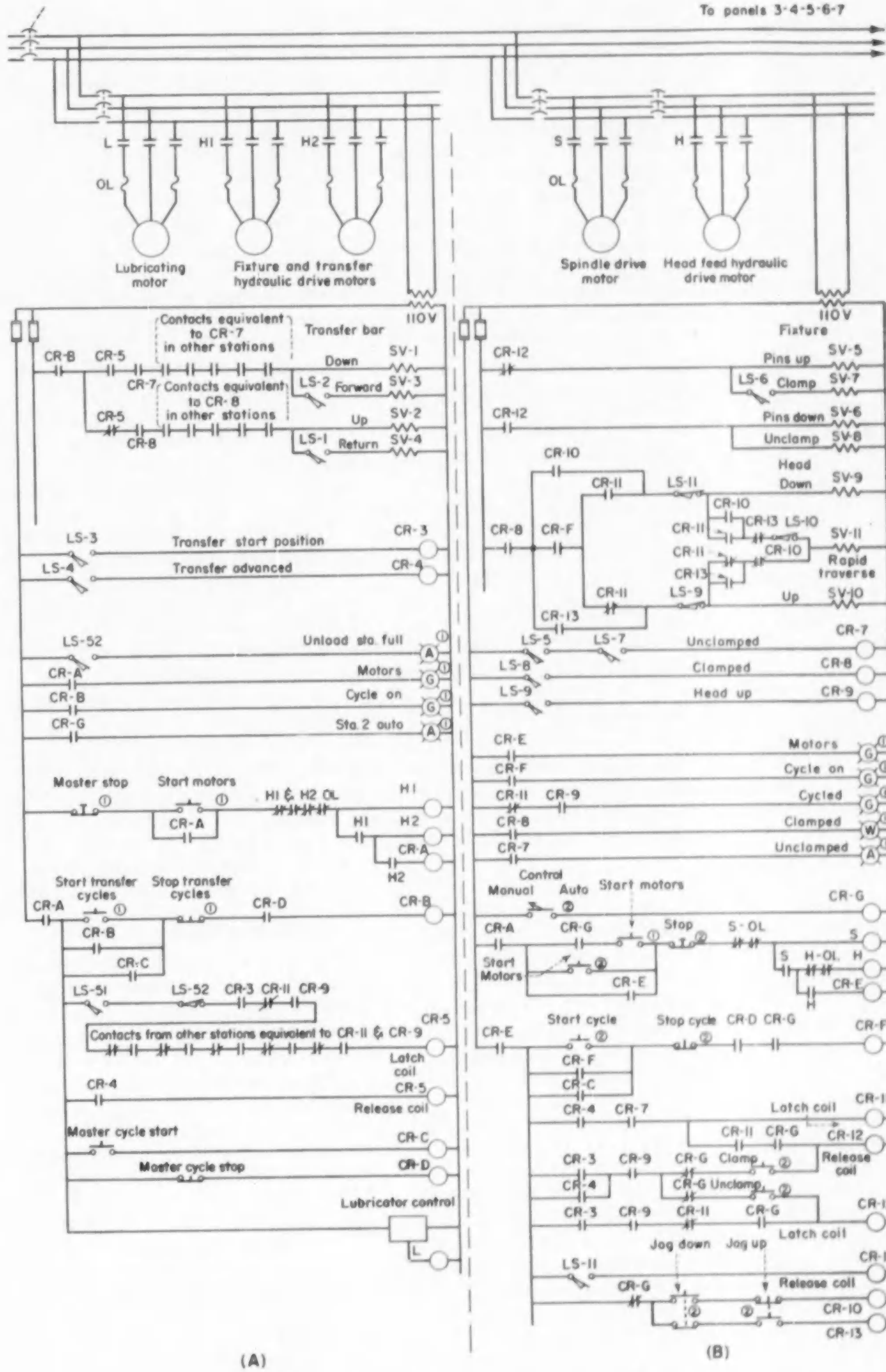


FIG. 6. Elementary wiring diagram for two control groups. (A) shows the circuit for the common station 1, while (B) shows the circuit for the first boring station, station 2.

in groups, depending on the required flexibility. Then the circuit is simplified to a process of latching and releasing relays at the proper times. This is the basis for the control, and should be as simple and direct as possible.

There are three major elements in this transfer machine: the transfer mechanism, the heads, and the fixtures. These are related to each other in the same way in each station, so that a single latching relay can be assigned to control each.

Relay *CR-5*, Figure 6A, controls the group of motions for the transfer cycle. When latched, this relay energizes *SV-1* to drop the bar to *LS-2*, which in turn energizes *SV-3* to advance it. When *CR-5* is released, *SV-2* is energized to raise the bar to *LS-1*, which energizes *SV-4* to return it.

Relay *CR-12*, Figure 6B, in the released position energizes *SV-5* to raise the locating pins to *LS-6*, which energizes *SV-7* to clamp the fixture. The fixture is unclamped by latching *CR-12*, which energizes *SV-6* and *SV-8*.

When relay *CR-11* is latched, *SV-9* and *SV-11* are energized, causing the head to rapid approach to *LS-10*. A dog holds *LS-10* open, causing the head to feed to *LS-11*, which releases *CR-11*. This energizes *SV-10* and *SV-11* for rapid return to *LS-9*. This limit switch opens to de-energize *SV-10* and *SV-11*.

CR-11 serves as a "memory" relay as well as to determine head direction. It is latched when a new part has been loaded; this is indicated by the transfer bar being forward and the fixtures being unclamped. The transfer must not run again until this part has been machined, and this can be assured by interlocking with *CR-11* and *CR-9*, since *CR-11* is released only at the end of a machining stroke and *CR-9* is energized when the head is up. Thus a combination of a NC contact from *CR-11* and a NO contact from *CR-9* indicates that the head has run, since a new part was loaded into the fixture. The latching of *CR-5* to run the transfer is dependent on this combination existing at each station. In Figure 6B, the same combination is used to latch *CR-12* to unclamp the fixture.

The circuit design problem is now reduced to operating *CR-5*, *CR-11*, and *CR-12* in sequence, and adding contacts directly in the solenoid valve circuits to provide additional safety for, and manual control of, the transfer machine.

The transfer bar must drop and advance only under these conditions: the cycle is *on* (*CR-B*), the bar is at the starting position (*CR-3*), the head cycle is finished (*CR-11* and *CR-9*), the load station is full (*LS-51*), the unload station is empty (*LS-52*), and the fixture is unclamped (*CR-7*). So a combination of these contacts is used to latch *CR-5*, and to energize *SV-1* and *SV-3* after the bar is down, closing *LS-2*.

After the transfer bar has advanced to *LS-4*, energizing *CR-4*, the fixture must be clamped, indicating to the head that a new part is in place. And after clamping, the transfer bar must raise and return. To accomplish this, *CR-4*, Figure 6B, latches *CR-11* as the signal to the head, and only if it does latch *CR-11* is *CR-12* released. If *CR-11* failed to latch, the head wouldn't run. And if *CR-12* were released (but without *CR-11* latched) the cycles would continue as though there were no failure—except parts would be going through station 2 without being machined. This is the reason for the seemingly unnecessary *CR-11* contact in series with the *CR-12* release coil. *CR-4* also releases *CR-5*.

The clamped condition of the fixture is indicated by *LS-8* energizing *CR-8*. So that with *CR-5* released and *CR-8* energized, the solenoid valves *SV-2* and *SV-4* are energized to raise and return the transfer bar.

The head must cycle when a new part is in place and the fixture is clamped. Thus the cycle is *on* (*CR-F*), a new part is present (*CR-11*), and the fixture is clamped (*CR-8*). Solenoid valves *SV-9* and *SV-11* are energized to start the head forward. At the end of the stroke, *LS-11* releases *CR-11* to return the head to *LS-9*.

The fixture unclamps if the transfer bar is at its starting position (*CR-3*), and the head has completed a cycle (*CR-9* and *CR-11*). This combination latches *CR-12* to energize *SV-6* and *SV-8* to unclamp the fixture.

If during the machining cycle *LS-51* and *LS-52* are again closed, *CR-5* would latch. Then when *CR-7* is energized to indicate the fixture is unclamped, the transfer bar starts a new cycle.

4. ADD MANUAL CONTROL

The fourth step is to add manual control to the existing automatic control while retaining the automatic safety interlocks. When tools are replaced or repairs made, it is necessary to operate parts of the machine out of sequence. Heads require jogging or inching control, and the fixtures must be operated if it is mechanically safe to do so.

When on manual control, *CR-G* is de-energized to prevent automatic operation and to make it possible to operate the machine with the manual buttons. The fixture can be unclamped or clamped with *CR-12* if the head is up (*CR-9*) and the transfer bar is at one end of its stroke (*CR-3* and *CR-4*).

The head can be run up and down with *CR-13* and *CR-10* if the fixture is clamped (*CR-8*).

• • •

Solving Scientific Problems

THE GIST: Using various approximation techniques, most scientific problems can be solved by repetitively performing the common arithmetic operations. Some of these techniques have been known for ages, but their application was limited by the immensity of many problems in terms of time and manpower. Then came the electronic digital computer. It was ideal for the task, since it could add, subtract, multiply, divide, and compare at extremely high speeds.

Not only can the modern scientific calculator solve problems that couldn't be solved before, but it has led the way to problems that hadn't even been thought of before. These problems range from the solution of systems of linear equations to the simulation of real-life situations. By outlining the general characteristics of scientific calculators and the types of problems they can handle, it is possible to specify the requirements for a good computer. Next month's article will survey the available calculators to see how they satisfy these requirements.

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Scientific calculators are the chief tools in the computation laboratories of university, government, and industrial research centers. Scientists, engineers, and mathematicians describe models of physical, empirical, or logical systems in language the machine can accept, insert numerical parameters, and obtain answers that may validate a theory on the basis of agreement with experimental results, provide the design parameters for all types of systems, or predict the behavior of devices as yet unbuilt.

The heart of a scientific calculating system is a large-scale, general-purpose, high-speed, stored-program, electronic digital computer, as first described by Burks, Goldstine, and von Neumann[2]. These computers rose out of the traditional sequential use of arithmetic, with internal decision making based on partial results. Of course, not all computers are selective-sequenced with a stored program. Other varieties of computing machine structures are inherited from different traditions. For example, the digital differential analyzer was developed by applying pulse techniques to the structure of an analog computer operational amplifier. These unusual off-shoots, however, are outside the main stream of present-day digital computation, and will not be discussed here. In general, they gain somewhat in calculating speed by performing operations simultaneously: but they lose flexibility, number handling, and decision making ability.

Figure 1 shows a flow diagram of engineering design procedure, which might be considered a complete scientific calculating system from the beginning of a problem to a completed design[3]. In this system, all of the blocks within the dotted lines can be handled automatically by high-speed digital scientific calculators. Those blocks outside the dotted lines have not been successfully attacked by machine techniques. They require human intervention. Thus a scientific calculating system has an electronic digital calculator embedded in a larger data-processing system, with interplay between the automatic computer and the mathematician or engineer.

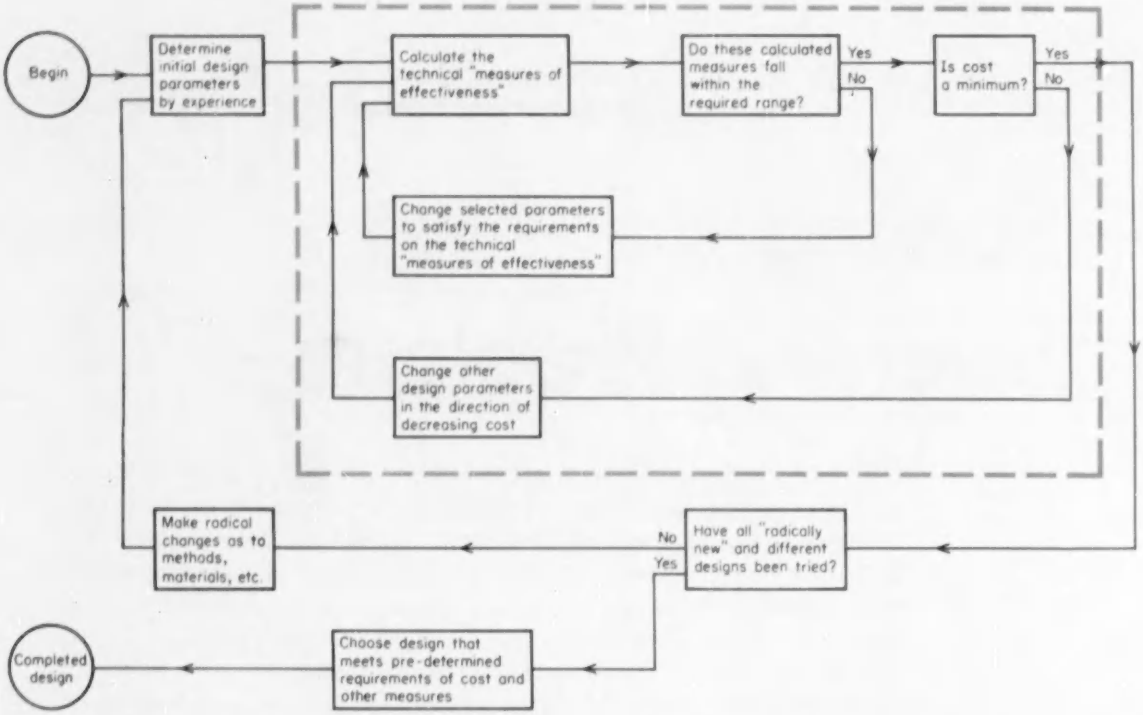

FIG. 1. Flow diagram of the design procedure in engineering. All operations enclosed by dotted lines can be handled automatically by high-speed digital scientific calculators. (From Bennett, "Faster than Thought"[8])

SCIENTIFIC VERSUS OTHER COMPUTERS

Most problems handled on a scientific calculator have never been solved before, at least in the size and scope achieved. And they are of a wide variety, ranging from the numerical solution of problems in aerodynamics and nuclear reactor structure, to the logic of switching circuits and computers themselves. Thus, most scientific calculators must be more nearly true "general-purpose" machines than business and "real-time" control data processors[1]. In many cases, the problems that are later transferred to one of the other types of data-processors are originally "simulated" on a scientific calculator.

Since scientific problems come from many sources, they tend to vary widely in size. Therefore, scientific calculators that are to compete with punched-card machines or desk calculators must handle short problems as efficiently as long ones.

The size and number of problems encountered in a computing laboratory differ greatly from those encountered in the "production" use of a data-processor on repetitive work. One large problem on a data-processor may actually consist of thousands of very small ones (individual payroll or aircraft position calculations), each handled within an overall framework. Scientific problems can have the same structure (for example, the solution of simultaneous equations under a multivariate combination of design parameters), but they also range upward to the solution of several-dimensional partial differential equations, where the result, after hundreds of millions of operations, depends on the very first operation in the sequence and all those in between. A scientific calculator located in a research laboratory or one servicing many varied sources of problems will probably be expected to solve problems ranging in size from a few thousand operations up to many millions. Some laboratories require a large-scale calculator to solve a hundred or more different and relatively small-size problems in a 24 hr period.

Comparative Problem Structure

Many problems solved on scientific calculators make little use of other than the arithmetic operations. In a study of three "typical" problems performed on the Maniac at the Los Alamos Laboratory of the Atomic Energy Commission, Herbst, Metropolis, and Wells[6] noted that the output of a mechanized "code analyzer" indicated no drum transfers and no magnetic tape handling. At the same time, in a "hydrodynamics problem", almost 65 per cent of the total computing time was devoted to multiplication and division. Granting a bias to small problems, and noting that the Los Alamos group in question does not operate in exactly the same fashion as other installations, it is still possible to apply these conclusions to a variety of small problems.

Thus most scientific calculations have been marked by a relatively small ratio of data processing and data transfer to calculation. When larger problems involving more complicated geometries are attacked, and it is necessary to call on secondary storage devices more often, this ratio may increase. Nevertheless, most problems on scientific calculators appear to be "process limited"—limited by calculating speed; while the newer business problems as performed on available machines are generally "tape limited"—limited by access time to secondary storage.

The major difference between scientific, business, and real-time data processors is in the input of information. Even when it handles the most elaborate table-formulating problem, a scientific calculator operates with only a medium amount of input and output data. A real-time computer, in a semi-automatic environment, will have only "exceptional" information transfer with the operators; but a business-data processor, first and foremost at this stage of development, must present written outputs to large numbers of people. The payroll record for 25,000 people may require for one particular procedure an input of several million characters from externally prepared records, with a comparable amount of output data processed by human operators. In contrast, the numerical solution of initial value partial differential equations on a scientific calculator may require no other numerical input than a few thousand decimal digits, and may run for hours, delivering an output at widely separated intervals.

For efficient operation, a scientific calculator must be able to handle innumerable repetitive calculations; examples include solution of aircraft dynamics for numerous parameter combinations, tracing of many rays through a lens system, or successive iterations to determine the solution of a classical boundary value problem. Because it deals with long sequences of operations, a detailed error analysis is required. This can be either preliminary, or carried along parallel with the actual computation. In any case, when the answer is obtained it is bracketed within values that express the spread built up by "round-off" and "truncation" error. No such error analysis is needed with real-time or business-data processors.

Another important point is the ease with which a problem can be expressed in machine language. Because of the variety of problems and the short operating time per problem, "programming" or "coding" a scientific calculator is generally more difficult than programming a business-data or real-time computer. However, mathematical notation is simpler and more nearly logical than the language of business, whose lack of as exact an external language tends to handicap the person using a data-processor on business problems. In general, the mathematician or engineer presenting a given sized problem to a scientific processor has an easier overall formulation and coding task than the business procedures specialist in the throes of translating a problem of the same size into concise machine language.

Most of the larger business-data processing problems require only one original problem formulation, which is carried over to a daily, weekly, or monthly performance for a long period of time. Scientific calculating laboratories, with scores of problems each day, require a much larger ratio of formulation and programming time to machine running time, even though the basic data-processing problem may require ten or more man-years before it can be set to run over a several-year period.

Based on available experience, an efficient and reasonably priced scientific calculator might boast of high speed, easy interchangeability of problems, flexibility, reasonable (but not vast) secondary storage, adequate (but not ultra-speedy) input-output, aids in error analysis and easy programming, Table I. As is pointed out in the next article, none of the commercially available equipments fills all requirements, but many offer a satisfactory compromise.

TABLE I—CHARACTERISTICS OF A SCIENTIFIC CALCULATOR

Structure of Computer	Nonspecialized general purpose calculator.
Arithmetic and Storage number systems	Binary or binary-coded decimal depending on need for large quantities of "logical" calculations; should have ability to handle aphabetical characters.
Arithmetic mode of operation	Preferably floating point for ease of set-up of different problems.
Size and number of problems	Many large and small problems of varied structure and type.
Amount of internal data processing and data transfer involved	Ratio of internal data processing and data transfer to calculation is relatively small.
Amount of input-output to and from human beings	Medium amount of data to and from human beings.
Need for easy methods of formulation and programming	Important because of large number of problems being solved.

THESE PROBLEMS CAN BE SOLVED

Most of the problems solved on scientific calculators have been in the fields of the physical sciences and engineering design. But the recent application of classical and newer mathematical techniques to the problems of business management has shown that these problems are also open to solution on the same machines.

Many problems in the physical sciences and engineering are *linear*, since the variables, and in some cases the functional derivatives, in the mathematical formulation occur in the simplest form, raised only to the first power. Other problems have mathematical formulations that can be "linearized" by neglecting certain nonlinear effects. In either case, the scientific calculator can solve large systems of linear equations (up to several hundred) to the required precision in a reasonable period of time. For example, complex problems in network analysis can be handled with standard "routines" already prepared for many calculators. Functional approximation techniques, such as polynomial, rational function, or continued fractions, can be applied to actual network synthesis, using the linear systems procedures to design a network with approximately the desired frequency- or time-domain response.

An important property of linear networks, whether electrical or mechanical, is the characteristic frequency of vibration. This frequency can be determined by using standard computer routines, developed for obtaining the characteristic values of matrices of orders up to several hundred. In servomechanism theory, the real and complex parts of the roots obtained by this procedure indicate system stability. While the extra instability introduced by the computer elements themselves sometimes makes it impossible to solve stability problems on an analog computer, digital scientific calculators are generally capable of developing a solution. Similar calculating techniques are used in such related problems as the binding energies of atoms in molecules, and the period of rotation of planets around the sun.

Nonlinear Problems

Although mathematical theory has not yet probed all possible nonlinear problems and the techniques for solving them, large-scale digital computers can handle nonlinear extensions of many linear problems. This means that physical and engineering problems, the majority of which are nonlinear, no longer need be linearized, and that for the first time problems can be attacked and solved in their original form, without a series of restrictive approximations.

For example, many former linearized solutions of ordinary differential equations are now being repeated in full nonlinear form. By selecting the proper "finite difference" approximations to derivatives, and using a small enough step size, results can be obtained that are as close as desired to the true solution of an equation. In fact, a general-purpose digital scientific calculator can be disguised as an electronic differential analyzer, so that problems set up for the latter can be just as easily solved on the former[7]. At the present time it is difficult to tie digital computers in with actual operating systems (compared with the relative ease of tying in an analog computer). However, this difficulty may be overcome if current experiments in directly connecting an ERA-1103, Figure 2, with actual equipment or with analog computers are successful.

Many large systems of ordinary differential equations have been solved in evaluating the response of aircraft and guided missiles. The technique has also been applied to such problems as economic cycle prediction theory and reactor transients.

Partial Differential Equations

In theory, at least, many of the ordinary differential equation systems can be solved with analog computers, punched-card equipment, or desk calculators, if enough time and manpower is available. However, this is not true with partial differential equations. With a few simple exceptions, these equations could not be solved without electronic calculators. Here again, derivatives are replaced by "finite dif-

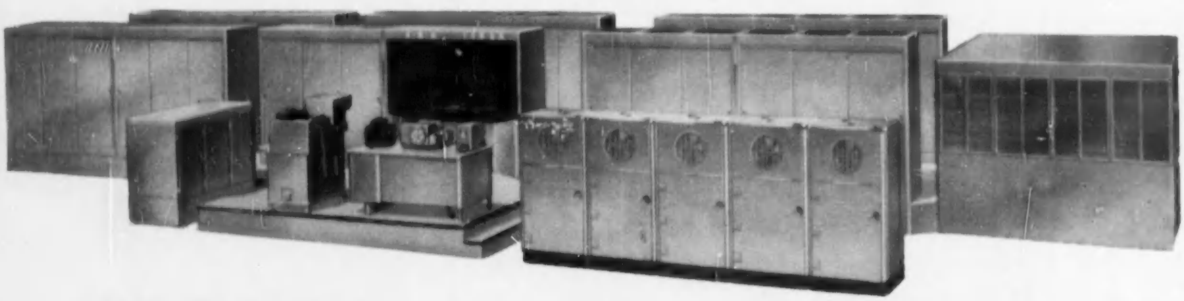

FIG. 2. Built primarily for scientific calculations, the ERA-1103 (UNIVAC Scientific), has special features for interconnecting the computer with external electronic equipment. When its chief competitor, the IBM Type 704, comes off the production line, there will be two commercially available real-time calculators that can double in handling such high-speed problems as missile systems control and simulation interconnections with analog computing equipment.

ferences" so that high-speed arithmetic operations can be performed on the discrete variables.

Partial differential equations are encountered in the theory and design of nuclear reactors, electromagnetic theory, problems in vibration and sound, quantum mechanics, fluid dynamics (such as the latest formulations of the weather prediction problem), and elasticity. The mathematical theory behind the numerical solution of nonlinear problems has not been studied as thoroughly for partial differential equations as it has for ordinary differential equations. Thus the solution of many problems requires further study, as well as direct calculation.

Simulation and Monte Carlo Techniques

In many cases it is possible to directly "simulate" a physical situation, thus not formulating the problem in a completely classical manner. An entire class of problems can be attacked by the "Monte Carlo" process, conceived by physicists at the Los Alamos Scientific Laboratory for solving complicated reactor shielding problems. The computer plays a "probability game", predicting the behavior of neutrons that are scattered from or absorbed by successive nuclei in the shielding material by following the "track" of the particles. Although generally more complicated statistical procedures must be considered, this technique of "model building", combined with the generation of "pseudo-random" behavior inside the computer, can directly simulate problems that otherwise could not be solved in a reasonable length of time.

On MIDAC at the University of Michigan, computer simulation was used to describe traffic behavior at a crowded intersection[8]. The success of this first experiment, which satisfactorily demonstrated the traffic variation with change in traffic-light timing, turn probabilities, and input of cars to the intersection, indicates that a similar simulation can be performed for a multi-intersection traffic grid. A multi-intersection grid cannot be described easily by classical techniques, so that direct simulation is probably the simplest method of solution.

In many cases, problem solutions can be expressed directly as "closed form solutions" that describe an answer in terms of the elementary functions, their powers, and integrals. While many such formula evaluations must be handled by high-speed scientific calculators, it often turns out that the original problem can be solved as easily by one of the newly rediscovered numerical-analysis techniques as by the evaluation of the classical closed form.

Numerous problems in "data reduction" should be included among these formula evaluations. Large quantities of numbers from a jet test stand, guided missile telemetering system, or some other large-scale experiment, must be inserted into a relatively simple formula to obtain key numerical measures of the experimental performance of the system under study. These problems require computer performance somewhere between that of a scientific calculator, where there is no absolute time deadline, and a real-time processor, where deadlines are continually arising.

Managerial and Social Science Problems

Modern scientific calculators have increased emphasis on the application of both classical and newer mathematical techniques to the field of management. Techniques range from the use of simple statistics up through highly complicated linear programming[9]. The latter involves the extension and application of the classical theory of linear inequalities to such diverse problems as the location of centralized warehouses and the assignment of air-crew personnel for highest overall fighting efficiency.

Since the linear programming problem involves maximizing or minimizing some "measure of effectiveness" (such as profit, or time and cost), the techniques cover a multitude of real-life situations (provided that the original formulation can be linearized). Many more nonlinear problems must await further mathematical theory before they can be easily solved on calculators. Other attempts, such as trials to determine the best combinations of stocks for an investment portfolio, must await better input information before satisfactory answers can be obtained.

Management also gains from the solution of the combinatorial problem. Here the machine is instructed to determine an optimum procedure by trying all possible combinations, or sampling desirable combinations, of a particular configuration. An example is an assembly line scheduling problem, where certain assembly operations must await the completion of preceding ones while others can all be performed at the same time. With complete knowledge of the priority relationships, and a high-speed automatic calculator to juggle the sequences within the limiting restrictions, large performance improvements have been obtained in several cases.

WHAT TO LOOK FOR IN A SCIENTIFIC CALCULATOR

Many industrial, commercial, and educational organizations are faced with the problem of deciding what size, kind, and make of scientific calculator or data processor they should obtain. Several thorough surveys of all possible equipments have been based on manufacturers' statements[10]. Of course, all manufacturers are willing to give a complete description of their equipments, based on *their* opinion of their performance. The next article in this series will attempt to add to manufacturers' statements some objective comments on available equipments.

At a Special Conference on Digital Computers and Data Processors at the University of Michigan last August, 17 users of equipment gave "Reports from the Users", which were taken down verbatim with questions and answers[11]. Where they apply, excerpts from these reports will be quoted.

Besides hearing the arguments of the various computer manufacturers, it pays for every incipient user to consult experienced and objective personnel, either inside or outside his own organization. A survey of the present users of equipment under consideration, including visits to installations, is imperative.

The first decision to make concerns the principal types of problems to be handled by the new equipment. Even this doesn't necessarily decide the pattern of equipment, since many business-data processors are also used for engineering calculations. At least one large installation plans to use a scientific calculator for both scientific and business problems, under the theory that a fast scientific calculator with suitable input-output equipment can perform better than any of the present business-data processors. (See the "Report" by H. R. J. Grosch of General Electric's Gas Turbine Div. on the proposed use of an IBM Type 704 calculator with Type 705 business-data processor peripheral equipment[11].)

The question of whether to rent or buy must be weighed in the light of both the financial and technical capabilities of the organization getting the calculator. Buying rather than renting is usually cheaper, but does not provide as much protection from technological obsolescence. Also, buying generally means the purchaser must furnish his own maintenance personnel. If a computer is to be altered for experiments with real-time applications, it usually must be purchased.

An operating electronics firm might tend to buy, an insurance company to rent; a university with an electrical engineering department capable of altering a computer might buy, and a nonengineering college might rent.

Programming Techniques

Original problem set-up procedures for computers required an instruction-by-instruction human hand translation of the problem into machine language. But with the advent of "automatic coding" techniques, in which individual external instructions correspond to groups of internal instructions, the computers themselves perform much of the clerical portion of programming and coding and at the same time avoid many human errors. The new user of a scientific calculator should make sure that the computing equipment under consideration can be adapted to automatic coding, or else be willing to spend many man-months on programming. Libraries of subroutines, automatic assembly programs, compilers, generators, translaters, interpreters, and all the other techniques developed over the last five years have shown that much of the difficult and time-consuming job of coding can be eliminated.

Input and output are often the weakest links in present-day equipment. On the average, 30 of the 40 monthly failures on the University of Illinois' Illiac are due to input-output. (See "Report" by Professor James Robertson of Illinois[11].) The average new computer user normally feels that a low-speed input or output device will not bottleneck his operation. But once the machine is being used regularly, external information handling delays soon prove intolerable. Regardless of machine cost, any stored-program scientific calculator should have an input speed of at least 200 decimal or alphanumeric characters, and an output speed of at least 50 characters. If the equipment is to be used in conjunction with available punched-card equipment, punched-card input-output is important. Otherwise, paper tape or magnetic tape input should be satisfactory.

Internal Computer Characteristics

Internal computer characteristics are important insofar as they affect the usability ease of a calculator and its electronic reliability. In present-day calculators, reliability varies inversely with the number of tubes, because of the inherent relative unreliability of vacuum tubes. Big advances in reliability are expected from the next sequence of computers, now on the drawing board, since they will have none, or only a few, vacuum tubes. However, preventing tube failure during operation is just as important. "Marginal checking" is one of the most common and workable preventive techniques. Computer voltages are varied during maintenance periods to determine which tubes or other components are apt to fail.

Although John von Neumann (considered the original designer of the present-day class of calculators) originally recommended the binary number system[2], it is worthy to note that he later participated in the Navy's design specifications for the NORC (Naval Ordnance Research Computer), built by IBM and now located at the Naval Proving Grounds, Dahlgren, Va. The NORC has a binary-coded decimal number system for easy external number handling. Similarly, although the original Princeton general-purpose design[2] recommended a fixed-point method of computation, with numbers in absolute values less than one, the NORC uses full floating-point arithmetic (fractional number plus decimal exponent). Both the binary-coded decimal number system and full floating-point arithmetic are extremely useful in scientific calculations, and a computer including both features should rate high. Built-in floating point saves time in problem formulation, since complicated prescaling of a problem where the partial results are obviously unknown is unnecessary.

Computer Storage

Particularly important in storage capacity is the relationship between the higher-speed, fast-access primary storage and the slower-speed, slow-access, but larger secondary storage. The earliest designs had at least 1,000 "words" or locations of primary-access high-speed storage, each containing the equivalent of perhaps 12 decimal digits. In a stored-program scientific calculator, 1,000 words is the absolute

minimum acceptable amount of direct-access primary storage.

The high-speed magnetic cores or electrostatic tubes that some computers use for primary storage have access times in the order of 10-50 microsec per piece of information. The cheaper machines often use the less expensive magnetic drum as a primary storage device. Since access to a particular piece of information on the drum must wait an average of a half-revolution (5 to 20 millisec, depending on drum speed), the latter machines may be from 100 to 1,000 times slower. The user of a slower-speed magnetic-drum machine should insist on more primary storage, since it is often possible to trade storage locations for time by tricky programming. For this reason, a magnetic-drum calculator should have at least 2,000 locations of drum storage, of at least ten decimal digits each.

The amount of direct-access primary storage often turns out to be insufficient to handle many quite ordinary problems, particularly if the machine uses binary arithmetic and needs complicated input-output conversion techniques. Then the user is forced to turn to secondary-storage devices, such as magnetic tape or the less useful punched cards or punched paper tape. Where machines have fast primary storage, drums can also be used as secondary storage.

Magnetic tape is useful in the many formula evaluation and data reduction problems that require large quantities of information to be handled. A prospective user should carefully weigh the relative speeds of the central processor, including primary storage, and the tape units. It is possible that the speeds are mismatched, and that the benefits are out of line with the cost of additional tape units. In some cases, the magnetic tape equipment, designed several years after the original computer, is much too fast, compared to the magnetic-drum primary storage, to be used as efficiently as its cost demands.

Instruction Codes

In the early days, a violent controversy raged between proponents of machine instruction codes using "one-address" and "three-address" logic. In one-address logic, an accumulator with a known address is the location of one of the operands or the result of an instruction, while in three-address logic, three addresses in each instruction locate the two operands and one result. One-address instruction logic is more flexible, but the three-address logic is easier to learn. With the advent of automatic programming, which may vary back and forth between one-, two-, three-, (or even more) address logic, the actual structure of a computer became less important. And the number of addresses in an instruction word is less important than the availability or nonavailability of coding techniques that permit the computer to perform much of the clerical labor required to prepare instructions.

In some scientific calculators, the digit length of the basic machine "word" can be varied by a factor of two. This feature is useful if primary storage is limited, but with adequate primary storage it will probably never be used. Some business-data processors, such as the BIZMAC and IBM Types 702 and 705, have a completely variable work length so that a number can be stored with an arbitrarily-sized sequence of digits. This would be extremely useful in experimentally determining round-off errors. However, the variable word-length procedure, requiring slower serial arithmetic, results in slower operation. This means that for scientific problems, the slower data-processors are noncompetitive with similarly priced machines designed as scientific calculators.

Optimum Cost and Size

Bigness, when equated with high speed and large storage, has a direct relationship to efficiency. Most experienced users agree that the larger and more expensive the machine, the lower the unit cost per operation.[12] This implies that one magnetic-core-storage calculator costing $1 million can do much more than four times the work of four smaller magnetic-drum calculators costing $250,000 each. (Of course, if four different geographical locations are involved, this might not apply.)

It is interesting to note that the NORC is about ten times faster on many problems than any other existing computer. Similarly, the design for the LARC (Livermore Automatic Research Computer), to be built by the Eckert-Mauchly Div. of the Sperry-Rand Corp., calls for over 25,000 words of high-speed magnetic-core primary storage, with decimal floating-point arithmetic. Obviously, such machines can be built at this stage of computer development. And

FIG. 3. The IBM Type 650 Magnetic Drum Calculator next year is to add alphanumeric data handling, magnetic-tape storage, floating-point arithmetic and a small quantity of magnetic-core storage (at increased rental) to its present numerical data handling, magnetic drum storage, and fixed-point arithmetic abilities. Although designed as a scientific calculator, it may be used more often as a business-data processor, mainly because there is no true data processor available in its rental range.

although the user may not be presently confronted with problems of the size of those to be solved on the LARC, he still should be prepared to see his present machine pressed to capacity as the skill of the operators and increased experience of the problem-posers result in more complex problems.

Reliability

In any type of computer, equipment reliability means the difference between smooth operation and a continuing struggle between user and equipment. Because of careful original design, even equipment developed several years ago has proven very reliable. For example, users of the Reservisor, a reservation accounting system at American Airlines, LaGuardia Field, New York, claim an average "down-time" of only 0.2 per cent out of each 22-hour operating day. This excellence was accomplished by building two identical computer and storage units, with a basic packaged construction. (Note that this low percentage does not include failures in input-output.

Similarly, the results of the acceptance tests for the ERA-1103 (UNIVAC Scientific), as reported by Richard Castanias of the Vitro Corp[11], show that the Eglin Air Force Base computer operated more than 43 hours with no errors, the only stoppages being due to paper-tape punch clogging. R. W. Bemer of Lockheed's Missile Div. noted that an IBM Type 650, Figure 3, operated consistently, unattended and without error, over weekends; and Professor A. J. Perlis of Purdue stated that the University's Elector Data Datatron had performed for one month with no errors in the central computer, and with only a few in the input-output equipment[11]. In all these cases, and in the other "Reports," input-output was consistently the chief source of failure. Those computers with internal checking devices performed even better. One user of both an IBM Type 701 and a UNIVAC reported that the latter computer, while much slower, was almost as cheap per unit operation. The UNIVAC's built-in checking prevented machine error propagation, while the 701 missed errors in the electrostatic memory because of the absence of built-in checks.

The latter difficulty can often be overcome by using programmed checks. A better way to reduce such errors is to use magnetic-core storage, as is being done on the Type 701's successor, the Type 704, and on the ERA-1103A and other machines. W. H. Papian of MIT, designer of the Whirlwind I core-storage system, the prototype for most that have followed, noted that there appeared to be a two-months' mean-free-path between errors on the Whirlwind core storage, and that failure came in the associated tubes rather than in the cores.[11]

All this indicates that purchasers or renters of scientific calculators should insist on extreme reliability from the central control, arithmetic, and primary storage units of their new systems, but at the same time should study carefully the performance of proposed input-output and secondary storage systems, still the main causes of machine unreliability.

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DR. JOHN W. CARR

John W. Carr got started on digital computers as an assistant on Project Whirlwind at MIT in 1948. In '49, a new MS in EE, he went to the Sorbonne on a Fulbright. While in Europe he put two months into learning the character of Cambridge U.'s new EDSAC, then returned to Whirlwind to set up its Subroutines Library. Carr's PhD thesis in 1951 dealt with solving partial differential equations with high-speed computers. In '52 he joined U. of Michigan's Willow Run Lab to ready MIDAC for use, later supervised the computer facility. Last year he became Assistant Professor of Mathematics at the University; he still consults at the Lab and runs computing courses for industry.

Two-Capacitor Method of Phase Shifting

SIDNEY A. DAVIS, Servomechanisms, Inc.

In ac servomechanisms, it is frequently necessary to shift the phase of the voltage on the motor main field winding with respect to the line. There is no simple means of maintaining this exact phase shift at all speeds. However, the two-capacitor method shown in the accompanying sketch gives excellent results for small instrument servomotors when adjusted with the motor stalled. In contrast with the more usual single-capacitor method, using two capacitors permits simultaneous adjustment of both voltage *magnitude* and *phase* on the main winding.

Table I lists a complete set of equations for establishing capacitor values. Once capacitance is determined, capacitor voltage can be calculated from the equations in Table II. The following two examples will clarify the use of this technique.

Example 1

The Bureau of Ordnance MK-7, 400 cycle, 115 v servomotor has a rated current of 0.110 amp at stall and a power factor of 0.5. Determine C_1 and C_2 and their voltage ratings if a 90 deg phase shift and unity magnitude ratio are to be achieved from a 115 v line.

Referring to Table I, use Equations 7 for 400 cps:

$$C_1 = 397.8 \frac{(0.5)\,(0.110)}{115} = 0.190 \text{ mfd}$$

$$C_2 = 397.8\,(0.110)\,\frac{(\sqrt{1 - 0.5^2} - 0.5)}{115} = 0.139 \text{ mfd}$$

and the Equations of Table II to determine the voltage across the capacitors:

$$V_{C1} = 115\,(1 + 1)^{1/2} = 162 \text{ v}, \quad V_{C2} = 115 \text{ v}$$

Example 2

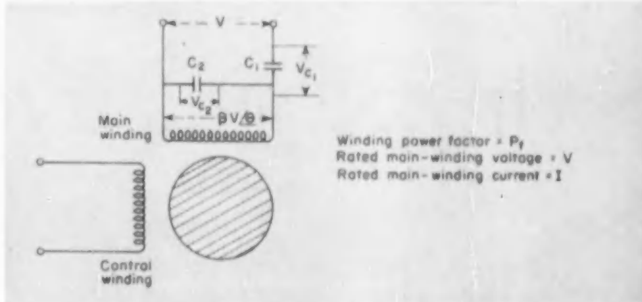
For a variation in the way these equations can be used, assume that a 90 deg phase shift is to be obtained with the motor discussed in Example 1 without using C_2 (in other words, C_2 equals 0). Determine the voltage impressed on the main motor winding under this condition.

Setting Equation 4 in Table I equal to zero,

$$0 = \sqrt{1 - Pf^2} - B\,Pf$$

Then B can be expressed by $B = \dfrac{\sqrt{1 - Pf^2}}{Pf}$

and where Pf equals 0.5, the motor must be designed to accept 200 v on its main winding.



Schematic of two-phase servomotor. Line voltage is shifted by angle θ and attenuated by B to rated motor voltage.

Table I—Capacitor Values for Various Phase Shifts and Magnitude Ratios

General Form—Any phase shift and any magnitude ratio.

(1) $$C_1 = \frac{B\,Pf\,I}{\omega V} \csc\theta$$

(2) $$C_2 = I\left[\frac{(\cos\theta - B)\,Pf + \sin\theta\,\sqrt{1 - Pf^2}}{\omega V \sin\theta}\right]$$

Special Form—For 90 deg phase shift and any magnitude ratio.

(3) $$C_1 = \frac{B\,Pf\,I}{\omega V}$$ (4) $$C_2 = I\left[\frac{\sqrt{1 - Pf^2} - B\,Pf}{\omega V}\right]$$

Special Form—For 90 deg phase shift and unity voltage ratio.

(5) $$C_1 = \frac{Pf\,I}{\omega V}$$ (6) $$C_2 = I\left[\frac{\sqrt{1 - Pf^2} - Pf}{\omega V}\right]$$

Special Form—Equations 5 and 6 for 60 and 400 cycles.

(7)	60 cps	400 cps
C_1, mfd	$2{,}652 \dfrac{PfI}{V}$	$397.8 \dfrac{PfI}{V}$
C_2, mfd	$2{,}652\, I\left[\dfrac{\sqrt{1 - Pf^2} - Pf}{V}\right]$	$397.8\, I\left[\dfrac{\sqrt{1 - Pf^2} - Pf}{V}\right]$

Table II—Capacitor Voltage Ratings

Across condenser C_1

$$V_{C1} = V\,(1 + B^2 - 2B\cos\theta)^{1/2}$$

Across condenser C_2

$$V_{C2} = BV$$

Communication Theory In Digital Systems

THE GIST: Communication theory has been derived from the composite work of mathematicians, statisticians, physicists, and electrical engineers. Its application immeasurably aids the efficient design and use of digital computers. For instance, considering the information content shows how messages can be reduced in length for minimum storage capacity and yet retain their full significance. A practical example, taken from quality control tests, is discussed in this article. It indicates several coding methods that save storage space.

Another example: as the digital data proceed from the input, through the computer, to the output device, these data suffer corruption of content through round-off and truncation errors. The extent and effects of these corruptive influences are also covered here.

The authors also consider programming, checking, transmission capacity, transmission rate, and the relationship of the major functions of a computer to the overall production of information useful to the operator but not available from the input data.

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Communication within a digital computer system is a three-path process. As shown in Figure 1:

- the operator communicates his problem to the computer
- extensive communication occurs within the computer during the course of the problem
- the computer communicates its results back to the operator or to some special system; for instance, a controlled machine.

Within the computer, as in most communication channels, the communicated messages consist of ordered sets of discrete symbols that represent the physical states of the computer's mechanism.

INFORMATION THEORY

For instance, consider a single symbol chosen from an available set of symbols—say a letter of the alphabet—where the choice of any one of the symbols in the set is assumed equally probable. If n is the number of symbols available, then this symbol can be chosen in any one of n ways. If the message contains more than one symbol, selection of the second symbol occurs in the same way. Thus, n, n^2, n^3, etc. represent the number of different possible messages containing one, two, three, etc., symbols.

The measure of the informational content of a message depends on the logarithm of the possible number of messages. It is reasonable to assume that a message's information content increases with the number of its symbols. For a message L symbols in length, the quantitative measure of the amount of information, H, equals $\log n^L$ or

$$H = L \log n.$$

Thus each symbol in the message conveys to a recipient an amount of information equal to $\log n$.

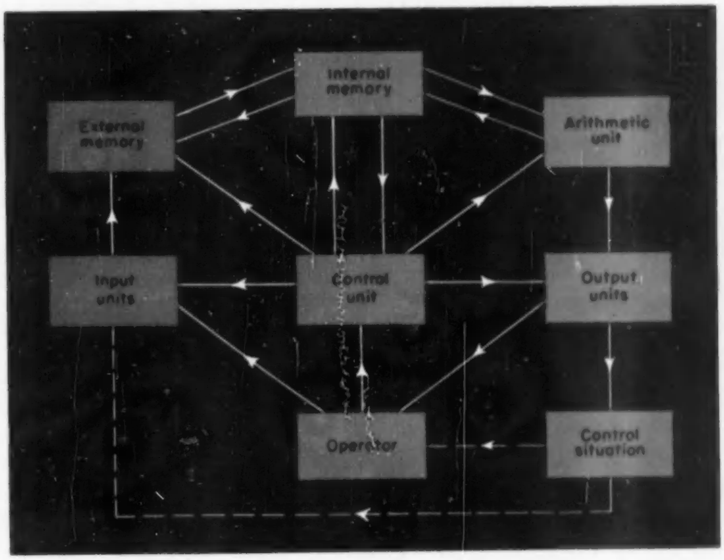

FIG. 1. This block diagram illustrates the three major paths of communication within a computer system. The first is from the operator to the input units, the second within the computer itself, and the third from the computer back to the operator or to a special control situation.

Of course, for this message to comprise significant information, the recipient must be able to decode the message and take seriously what it says, but not be able to predict it in advance. If the logarithms are taken to the base 2, then the measure of the information is in binary units, or *bits*. This simplest choice, between two equally likely symbols, gives

$$H = \log_2 2 = 1 \text{ bit}$$

as the amount of information conveyed per symbol.

Non-uniform Probability

Generally, not all symbols are equally probable. For example, in the English language not all letters occur with equal frequency. In fact, if a message is long enough, one predicts not only the letter frequencies, but the frequency with which one letter follows another. For example, *h* frequently follows *t*, and *u* always follows *q*. The effect of this prediction is to reduce the information content, because part of the message tells the recipient something he already knows. The previous definition of information content now requires modification.

For messages of n symbols, where P_i is the probability of the ith symbol, the information content, H, per symbol becomes[1]

$$H = -\sum_{i=1}^{n} P_i \log_2 P_i.$$

H is maximum when all P_i are equal, and under this condition its maximum value equals $\log n$.

Information Storage

The problem of storage consists of reducing the message to the shortest length that still permits highly probable reconstruction to its original informational content. Then less storage capacity will be required than for the original message. Note the fundamental distinctions between the informational content of a message and the capacity required to store this message; and also between the information-generation rate of a message source and the capacity (as a rate) of a communication channel required to transmit information.

A message in the English language does not require a full 26-state capacity to store each letter of the message. Portions that are redundant or devoted to known characteristics of the probability structure may be left out. The most efficiently transmitted or stored message is one whose every part is independent and uniformly random.

Coding for Minimum Capacity

The efficient *coding* of non-random messages equalizes the probabilities of all possible coded messages, permits higher informational content, and reduces the storage capacity required. We may consider a problem of coding messages with unequal probabilities. The information comes from a quality control test and the results go into a binary storage bank:

QUALITY	PROBABILITY
A	0.80
B	0.15
C	0.04
D	0.01

For example, a sequence of 28 tests results in the following typical distribution, grouped in blocks of four for convenience:

AAAB AAAA ACAA AAAA BAAA AAAA BAAD
(28 symbols)

If the following straight binary code is attached to each symbol, (A—11; B—10; C—01; and D—00) 56 storage bits are needed to store the 28 symbols, or 2.0 storage bits per test.

Straight binary sequence:

11111110 11111111 11011111 11111111
10111111 11111111 10111100 (56 bits)

But another code can be used that examines sequences of up to four symbols until the first non-A symbol (if any) is encountered. Here, the position and letter of the non-A symbol follows these codes:

POSITION	CODE	LETTER	CODE
1	100	B	0
2	110	C	00
3	111	D	000
4	101		

The blocks are scanned until the non-A symbol occurs and its position and letter are noted by the code. If all four of the symbols are A's, then only code 101 is used. Note that each of these position-identification groups starts with a *1*. Here is how the test sequence looks with this second code:

10101011100010111101011010111000

Thus, in reading the coded message, the first three binary digits give the location of a non-A symbol, and the following *0*'s identify the letter. Then the next group of three digits starting with a 1 gives the next position information.

The short sequence above requires $32/28 = 1.15$ bits per symbol. This appears fairly efficient in view of the low-probability *D* in the sequence. Another alternate code, with an average of 1.26 bits per symbol, derives from this simple code:

A—1; B—01; C—001; and D—0001

Here, the *1* denotes the end of a symbol code and so the sequence can be deciphered. Note that the symbol with the highest probability has been assigned the least number of digits. This procedure reduces the number of bits per symbol.

A practical example of the technique of using only a small amount of storage is illustrated by the case of storing a particular mathemathical function. It is not necessary to store a complete table of values for the function; only the coefficients of the power series representation need be stored.

Transmission Capacity

The central problem in communication is to transmit messages efficiently through a noisy channel. Figure 2 shows the path of a signal from the source to its destination and the introduction of noise within the transmission channel. Noise, or random-signal generation, occurs in transmission and storage as a result of random thermal currents and unexpected combinations of circumstances, the statistical failure behavior of large groups of components, decay of storage elements, and other natural departures from ideal behavior.

The basic parameters that determine channel capacity for the transmission of information are the bandwidth and the signal and noise powers[1]:

$$C = B \log_2 \frac{S + N}{N} \cdot$$

Here, *B* is the channel bandwidth in cycles per sec, S and *N* are the signal and noise powers, and C is the capacity in bits per sec.

COMMUNICATION— FROM OPERATOR TO COMPUTER

The operator communicates his problem to the computer through a keyboard, which records the problem on punched cards or paper tape, or on magnetic tape. As a portion of the computer's external memory, this record constitutes a source of numbers and instructions for these numbers.

Instructions

The computer can interpret and execute only simple operations. Therefore, a difficult part of the communication process involves the simplification of instructions into a form that the computer can

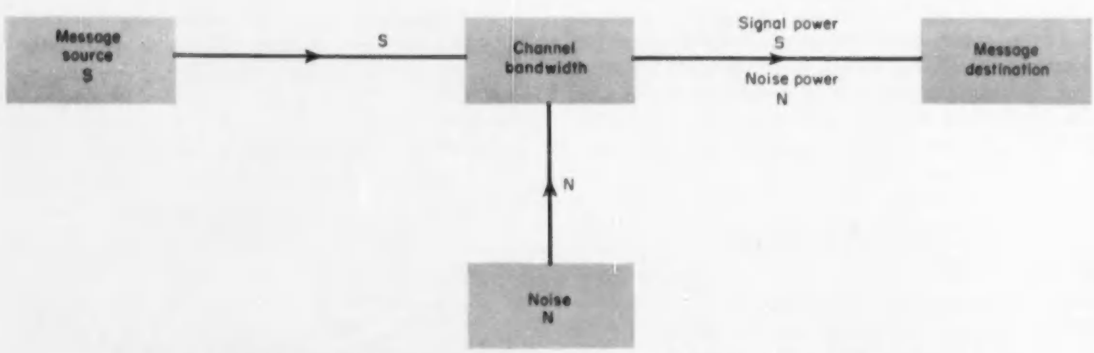

FIG. 2. As the digital message proceeds through the channel on its way to the destination it becomes corrupted by various sources of noise, as shown in the block diagram above. Typical sources of noise are: power-line transients, thermal noise, and faulty components.

understand. For instance, the computer understands such simple commands as:

▸ add the number stored in memory location 010 to the number stored in memory location 011, place the sum in memory location 012, and then perform as an instruction the quantity stored in memory location 030; or

▸ if the number stored in location 012 exceeds the number stored in 013, perform as an instruction the quantity stored in 031; otherwise go to 032.

In terms of striking keys, these instructions may be represented by:

1010011012030
5012013031032

where the initial *1* means add and *5* means compare.

Programming

Most computers that have been operating for some time acquire libraries of instruction tapes and card decks that carry programs for a wide variety of computations. All the computer needs are the appropriate tape from the library and another tape that specifies the numbers for the problem. Or it may combine several library tapes with the aid of a super-program tape.

Interpretive programming may be used to simplify communication between the operator and the computer. The library program tells the computer not to obey its own instructions literally, but to interpret them as relatively short stored sub-programs for a variety of operations. Although the effective ability of the computer is expanded, it is at the expense of slowing down the computation because of the time required for interpreting.

In the program-checking interpretive mode, the computer keeps track of many things that might otherwise get lost in the normal execution of the problem. Among these items are:

▸ the identity of all memory locations whose contents have been changed during the computation

▸ printout of all individual arithmetic results, together with instructions executed in the sequence

▸ finding errors in programs, where the programmer did not command the machine to do what he thought he was commanding it to do.

When a computer operates in the interpretive mode, it can be made to accept almost any language, including algebra. Thus, computers that have the proper programs solve sets of algebraic equations when given the equations in literal form. Or the computer can be made to evaluate a definite integral from the mathematical form of the integral even when it contains transcendental functions.

The informational capacity of the input channel determines the speed at which data can be supplied to the computer. Ideally, the input rate should be so fast that the computer does not waste time waiting for data. Unfortunately, this aim is often not realized because many types of input devices are relatively slow.

COMMUNICATION—FROM COMPUTER TO OPERATOR

The control panel communicates a small amount of information to the operator through its neon indicators. These lights show (in binary code) the contents of the arithmetic and instruction registers and program counter, and indicate the type of operation being executed. Although these lights flash much too fast to be read during the course of the computation, they freeze into a complex pattern when something goes wrong and the machine stops. This pattern can be read for the clue to the source or location of trouble.

The computers rapidly delivers information to a typewriter connected directly to the output of the computer; but this typewriter is still relatively slow. Directly-connected high-speed printers or output tape accept large quantities of information at the fastest rates. The information, if taped, subsequently operates a printer at some slower rate.

COMMUNICATION—WITHIN THE COMPUTER

The computer acts as a communication channel from the input device, on which the problem is fed into the machine, to the output device, on which the machine delivers its results. The details of the communication process depend on the nature of the computer's circuitry.

Fundamentally, all existing electronic digital computers operate on binary signals. All communication, both internal and external, is couched in binary terms. Thus, the input keyboard codes the input characters in binary terms and the output printing device decodes them and prints the appropriate characters in the decimal system.

The binary character of the codes minimizes the chance that noise can cause an error and, ordinarily, errors where one state is confused with another arises from transients rather than noise. Less frequent are errors due to faulty components.

Signal-to-Noise Ratio

The large signal-to-noise ratio that exists in computer circuitry indicates a high information-rate capacity. This capacity could be increased and a higher speed of computation obtained by increasing bandwidth or using a many-state representation instead of the present binary technique. Here:

▸ shorter or steeper pulses and higher clock signal rates increase the bandwidth, but

▸ multi-state operation of tubes and storage devices is not reliable with presently available components.

Simplicity and the relatively low efficiency of the high signal-to-noise ratio of a two-state system form a compromise with the conflicting demands of equipment cost and reliability. Redundancy procedures and equipment in the computer combats random equipment and component failures, where these

failures may be interpreted as a noise-like interference. Such redundancy is found in the coding procedures and other means of checking built into the computer.

CHECKING

Checking procedures assure accuracy in digital computers. Many different methods, for different reasons, are used:

- the *parity check* appends an extra digit, as needed, to the binary code for each character, so that all characters are represented by an odd (and therefore never zero) number of pulses. Thus, if any one digit is accidentally altered or if all of the digits are dropped, the error can be detected and the computation tried again automatically. Should the error persist, the computer sounds an alarm
- the *echo check* transfers the entire received information back into the source to see whether it is exactly the message that was sent
- a *marginal check* alters the heater supply and the *B* supply voltages in one section of the computer after another, thus exposing incipient failures, which might appear during computation
- *mathematical checks*, such as the substitution of the root of an equation back into the equation.

ERRORS

Nearly all errors made during a computation are the fault of the human operator. The most experienced programmers seldom see a problem run correctly the first time. Debugging a program is a matter of successive approximations, during which the computer may be the undeserving object of a good many hard feelings. Once the program has been debugged, however, two other errors arise:

- quantizing error, resulting from round-off due to the limited number of figures that a computer handles, and
- truncation error, the result of the computer's limited (but high) speed.

Quantizing Error

Quantizing, or round-off, error occurs because a continuous variable is being represented by a discrete succession of values, each of which can take on a limited number of different values. In digital computers round-off errors act like continuous noise. The effect builds up as long as the computation continues, rendering uncertain more and more of the digits at the least significant end of the numbers.

Thus, while ten digits seems adequate for a desk calculator, it is not so for an electronic digital computer, which executes so many more operations per final result that it often needs to carry additional digits. Because the quantizing error grows approximately with the square root of the number of arithmetic operations, the computer needs at least three more decimal digits than does a desk calculator.

Truncation Error

Truncation error is due to the computer's limited speed, which necessitates representation of a continuous wave by a periodic succession of sampled values. Truncation error occurs principally in the solution of differential equations and in the computation of integrals and is a result of having to use a finite value for the increments of the independent variable.

In principle, one might use as small an increment as one pleased, but an increment one-fourth as large requires four times as many steps of integration. This would lead to four times as many round-offs and, on the average, twice as large an expected round-off error. Thus, the numerical analyst, when setting up the program for computer solution, balances carefully the effects of truncation and quantizing errors against the cost of computing time. This cost may suggest the acceptance of a large truncation error—thereby keeping down the total number of operations that a computer must perform.

Error Analysis

But round-off errors are not necessarily independent and random; that is, they are not necessarily uniformly distributed between plus and minus half a unit in the last place. These errors may occur time after time in the same direction and build up to a larger total error. This situation must be guarded against carefully, for it may invalidate twice as many figures at the end of the result as would otherwise be expected. Thus, round-off errors limit the accuracy of the final result, just as the noise level limits the fidelity or the rate of transmission of information in a communication system.

INFORMATION RATE

As we have seen, the input message becomes more and more corrupted by noise as the computation progresses. Thus, the effective signal-to-noise ratio at the output may be expected to be so much lower than the effective signal-to-noise ratio at the input as to be effectively independent of the latter. The output signal-to-noise ratio in any particular result may, therefore, be described as the ratio of that result (which should be of the order of unity) to its standard deviation. If the latter is due to random round-off errors, the signal-to-noise ratio, which may be defined as starting out after one arithmetic operation in a computer carrying n decimal digits, at about 3×10^n, on account of an assumed round off to n digits, will fall as $t^{-1/2}$ where t is the time, expressed in units of arithmetic operations contributing to the round-off error in the final result. If m digits of the final result are reliable and this result is close to unity (good scaling of the variables requires that the numbers be kept close to the maximum value that the computer can handle), the output signal-to-noise ratio may be about 3×10^m.

Without extensive use of mathematical theory of communication[1], it is possible to see that as a communication channel between the input and the output, its informational capacity is m decimal digits per such result. Of course, under the guidance of a different program, the computer could have transmitted a vastly greater amount of information from the input to the output in the same length of time; e.g., it might simply have transferred input data directly to the output and done no computing. Thus, we see that any computing the computer does results in a loss of information!

This means that the result is implicit in the input program and input data and, in fact, a more exact result is implied by these data than the result obtained by the computer. A computer carrying more figures would have achieved a more accurate result. In fact, no computer at all is necessary. The programmer might have carried out his program (if he had enough time) with the aid of many pencils (and much paper) and obtained a result with arbitrarily great precision. A computer's real value is its speed in obtaining a result whose relationship to the input data is so obscure that the user of the computer can guess only very roughly what it will be. Thus, barring his resorting to other ways of estimating the result, the user, when he sees this result, gains a certain amount of information which is determined by the difference between his prior uncertainty as to the result, (expressed as the range of positions in which the first non-zero digit of the result will fall) and the number of digits of the computer's result in which he is interested or in which he places credence. Thus, the computer gives many decimal digits of information to the user for each successive result.

It is interesting to apply this approach to the case of the desk calculator, which may be slow enough for the operator to estimate the result fairly accurately before the machine has finished computing it. This ability of the computress to compute rapidly in her head reduces the amount of information the desk calculator gives her and it acts as a check against errors. The operator of an automatic computer, however, is not able to keep up with the machine unless he has laboriously computed a check solution in advance to make sure the computer is doing what he intends, and so he gets more information from the machine at the expense of uncertainty about the result's accuracy.

The point to be emphasized here is that the computer can in no case be regarded as generating information. The computer comes closest to doing that when it is executing a program for the generation of random numbers, but, actually, the numbers it generates are completely determinate, just as are all of the things an automatic computer does when it is operating properly. Hence, the user could generate the same "random" numbers by carrying out the computer program himself with paper and pencil. Although the numbers are not really random and spontaneous, they may well possess the proper statistical characteristics that are required in their application. Furthermore, there are sometimes advantages to being able to repeat the same sequence of random numbers for use in a number of different computations.

The only time that a computer could be regarded as spontaneously generating information would be when the program guiding it is not known but the significance of the result is known. For this to happen, it would be necessary to have genuinely random elements entering into the creation of the program and, at the same time, an ability of the computer to explain the significance of its result. A computer vastly larger and more complex than any we have today would be required to realize such a generation of information by a computer, though it is not inconceivable that we shall one day have computers which are capable of a creativity comparable in degree with that of a human being.

LEARNING

The ability to learn represents a lower form of intelligence than the ability to create, with which we have just dealt. Experiments have already been done with computers that learn to "adapt" to their environments, though the range of their responses to their environments so far has been rather limited. The computer is programmed to try out its various responses in a random order. Those responses that are rewarded by some measure of success (the computer must be told how successful it was in the situation with which it was confronted) it tries more frequently; those that are unsuccessful it tries less frequently. In this way, it can adapt its response pattern to a changing external environment, which represents a very rudimentary form of learning.

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2. *INFORMATION THEORY*, S. Goldman, Prentice-Hall, 1953.

MEYER LEIFER

N. M. BLACHMAN

HOW STABILIZATION IMPROVES CLOSED-LOOP OPERATION

Putting Stabilization To Work

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THE GIST: Last month the authors expressed the operation of closed-loop systems in terms of stability and damping. Now they describe actual stabilizing and damping techniques that can improve the dynamic operation of servos. Network stabilization, one of the most frequently used methods, is considered at length. Normally, these corrective networks are designed for a dc servo. But they are easily converted to an equivalent ac circuit for use in an ac servo. Two tables in the article show the steps for designing a dc stabilizing network and for converting it. A third table illustrates eight other ways to improve servo operation. This latter table includes brief descriptions, advantages and disadvantages, and illustrates each device or circuit.

As a final practical contribution, the authors apply the damping network to a synchro-type repeater servo. They work out the transfer function of the uncorrected servo; determine the corrective positive phase shift; design the network to give this shift; compute the values of the resistance, capacitance, and inductance; and indicate two different ways to use this circuit in the ac servo.

STABILITY AND DAMPING

A servo system requires adequate stability and damping, characteristics that depend on such dynamics as amplifier gain, motor and load inertia, and friction. Often a system must be adjusted to meet design requirements. Generally, the major adjustment is made by:

- ▶ introducing a positive phase shift angle to partially compensate excessive negative phase shift of the open-loop transfer function of the system, or
- ▶ increasing the *effective friction* in the system.

Probably the most advantageous procedure involves network stabilization, properly designed combinations of resistance, inductance, and capacitance giving the necessary positive phase shift. This approximates true *error-rate damping*, and will be discussed in detail along with a practical example.

However, the many ways to adjust the effective

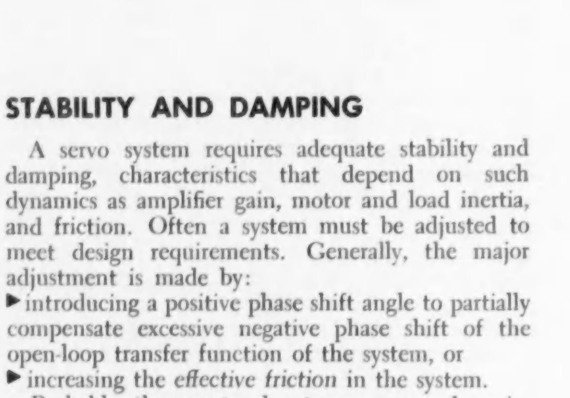
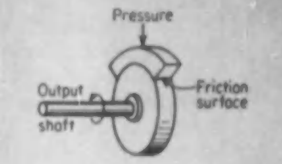
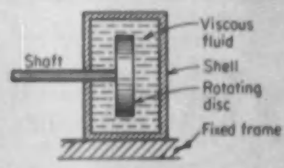
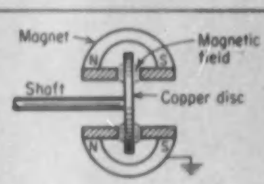
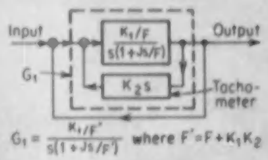
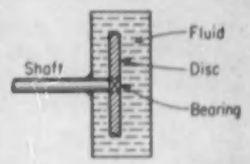
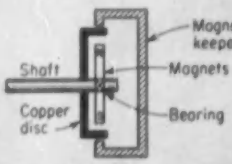
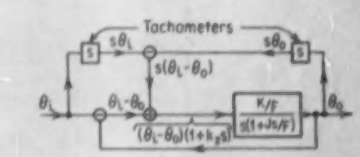
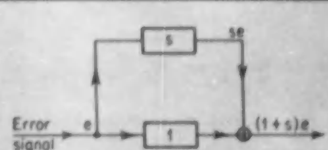


FIG. 1. Typical Nyquist plots of an open-loop transfer function, useful in determining the relative stability of a closed-loop system. Because the system is third-order, the curves asymptotically approach the minus 270 deg axis as the magnitude falls to zero. Curve 1 represents a stable system—it does not enclose the $1\angle{-180}$ deg point. Curve 2 shows instability—it encloses the point. Phase margin (PM) and gain margin (GM) show relative stability—both are positive. When gain increases, they become negative and servo is unstable.

TABLE I EIGHT WAYS TO IMPROVE SERVO OPERATION

THE METHOD	CONSIDERATIONS	DEVICE
1. **COULOMB FRICTION** obtains from suitable friction surfaces on the output shaft. The resulting force opposes the shaft motion. A dead zone exists where small oscillations are permitted.	Inexpensive and simple, where accuracy requirements are not important. But wear limits life; difficult to adjust and maintain; wastes output power; and introduces static and velocity positional errors.	
2. **FLUID VISCOUS DAMP** increases effective friction. Shaft rotates disc inside a cylindrical shell filled with viscous fluid. Rotating disc exerts restraining torque proportional to velocity.	Simple, rugged, has long life. Large F coefficient obtainable in small size. But adds inertia to motor rotor. Fluid may leak; fluid viscosity may be temperature sensitive; and some output power is wasted.	
3. **EDDY CURRENT DAMP** gives same effect as 2, but uses magnetic construction. A copper disc rotates perpendicular to a magnetic field. Induced eddy currents set up magnetic field, and exert retarding force.	Easily assembled; there's no fluid to leak out. Good reliability; but inertia added to motor. For given size the damping is limited; temperature varies resistance of disc and hence damping.	
4. **VELOCITY FEEDBACK** gives voltage signal from tachometer proportional to output shaft velocity. This arrangement increases effective friction coefficient.	No large power waste; and coefficient F easily adjusted by voltage divider or transformer at tach output. But may be expensive, and of relatively large size; extraneous electrical noise may be present.	
5. **VISCOUS ACCELERATION DAMP** is similar to 2, but shell fixed to shaft and disc free to rotate. On sudden velocity changes inertia of disc gives restraining torque proportional to difference in relative velocity between shaft and previous disc speeds.	Energy dissipation only when motor suddenly changes speed, and no additional velocity error is introduced. However, heavy disc increases system inertia, and bearings are difficult to manufacture.	
6. **MAGNETIC ACCELERATION DAMP** gives same effect as 5. Construction similar to 3, again disc is free to rotate. At sudden velocity changes the device creates a torque proportional to difference in relative velocity.	No additional error introduced; energy dissipated only during acceleration. But strength of magnet limits damping torque; and device adds inertia to motor rotor.	
7. **TRUE ERROR-RATE** derives from two tachometers that give velocity difference between input and output. Overall effect introduces $(1 + k_2 s)$ term in numerator of system transfer function to give corrective (positive) phase shift.	Arrangement gives ideal correction, but requires two matched tachometers to get rate signals of input and output velocities. Also needs additional comparators to obtain difference voltages.	
8. **ALTERNATIVE ERROR-RATE** method adds derivative (lead) signal to error signal and gives positive phase shift. This improves phase and gain margins.	Block s might be dc operational amplifier. But this requires vacuum tubes and power supplies.	

friction also have their uses. Table 1 includes these methods, illustrates typical devices, and points out their advantages and disadvantages. In addition, this table includes *error-rate damping* methods other than stabilization networks.

A Nyquist plot (Figure 1) shows the frequency response of the open-loop transfer function of a third-order servo. This diagram discloses several bits of useful information about the operation of the system when the loop is closed. Among these points:

- whether or not the system will be stable, and
- if the system is stable, whether there is enough margin of stability to assure adequate performance under all conditions

A single-loop servo is stable if the open-loop transfer function does not enclose the point $1 \angle -180$ deg when plotted on the Nyquist diagram, as in Figure 1. Here, phase margin and gain margin indicate the extent of stability.

The amount of damping determines the response of the closed-loop system to transient disturbances. Proper damping assures fast response, usually with one or more overshoots as the output seeks the position commanded by the input.

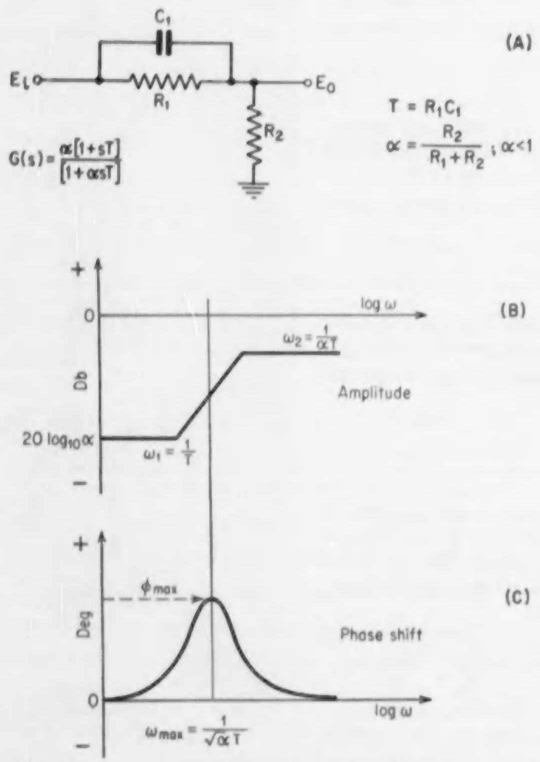


FIG. 2. A dc lead network (2A) uses a combination of resistance and capacitance to obtain the rising amplitude (2B) and positive phase shift (2C) that characterize a lead network.

STABILIZATION TECHNIQUES

Improved stabilization and damping result from three major techniques:

- Coulomb friction—here, a *constant* mechanical force opposes the motion of the output member. This type of friction is essentially *independent* of the velocity of the output, but may have a dead zone that allows oscillations of small amplitude, which may be desirable. Undesirable, however, is wasted power at the output, and a constant uncertainty in position due to coulomb friction. Coulomb friction is shown in Table 1.
- Velocity damping—this method develops a force *proportional* to the velocity of the output and opposes the output motion. Velocity damping may waste output power, and also introduce a positional error. This method of damping can be developed in several ways, as shown in Table 1:
  - fluid viscous damping (mechanical)
  - eddy current damping (magnetic)
  - velocity feedback (electrical)
- Error-rate damping—in this case, an ideal arrangement would combine the error signal with its rate of change and develop a force opposing the output motion. The rate of change introduces a positive phase shift angle in the through loop that helps to offset some of the negative (lag) angle produced by the motor and load. Error-rate damping eliminates velocity errors and does not waste output power. Table 1 lists the several ways to obtain error-rate damping:
  - viscous acceleration damping
  - magnetic acceleration damping
  - electromechanical (two methods)

Networks provide a nearly ideal error-rate damping and have certain advantages over some of the above methods.

DC AND AC SERVO SYSTEMS

Servo systems divide into two categories with respect to their power source:

- dc servos use dc voltages as their power source. But the instantaneous value of the actuating signal varies with time, as in the case of periodic changes in the input amplitude during a frequency-response test.
- ac servos, on the other hand, use a high-frequency carrier voltage (60 or 400 cps) as the source of power. Here the lower-frequency actuating signal amplitude-modulates the carrier. But the system responds only to the *envelope* of the modulated wave.

Frequency response of ac and dc systems are plotted in identical ways, for only the information—carrying, or modulating signals are of interest in checking stability and damping on a Nyquist diagram, and the dc source and the high-frequency carrier voltages are extraneous. The circuits for particular transfer functions, however, differ for ac and dc servos.

TABLE 2 FACTORS IN DESIGNING A LEAD NETWORK

THE REQUIREMENTS	THE CHOICE	WITH THESE CONDITIONS
INPUT IMPEDANCE TO AMPLIFIER	R_2	R_2 will be the minimum input impedance to the amplifier at the highest frequency.
MAXIMUM LEAD ANGLE — ϕ_{max}	R_1	arc sin $\phi_{max} = \frac{1-\alpha}{1+\alpha}$, where $\alpha = \frac{R_2}{R_1+R_2}$. Then pick R_1, since R_2 is known.
FREQUENCY AT WHICH MAXIMUM LEAD ANGLE OCCURS — ω_{max}	C	$\omega_{max} = \frac{1}{\sqrt{\alpha}\,T}$, where $T = R_1C$. α and R_1 known. T determined from ω_{max}, and then C from time constant, T.

DC LEAD NETWORKS

The resistance-capacitance combination shown in Figure 2A produces a positive phase shift as required from a lead network. In fact, this widely used circuit serves as a prototype for many other types. Here, the transfer function, G (s), equals the output voltage, E_o, divided by the input voltage, E_i, or

$$G(s) = \frac{E_o}{E_i} \tag{1}$$

where s equals $j\omega$, the frequency variable.

$$G(s) = \frac{R_2}{R_2 + \frac{R_1}{1 + sCR_1}} \tag{2}$$

$$= \frac{R_2(1 + sCR_1)}{R_1 + R_2 + sCR_1R_2} \tag{3}$$

Let $\alpha = \frac{R_2}{R_1 + R_2}$

and let $T = R_1C$; then factor $R_1 + R_2$ from the denominator of Equation 3; the transfer function becomes:

$$G(s) = \frac{\alpha(1 + sT)}{1 + \alpha sT} = \frac{\alpha(1 + j\omega T)}{1 + \alpha j\omega T} \tag{4}$$

The frequency response of this network is shown in the Bode diagram (Figures 2B and 2C) as determined from Equation 4 (see *How Stabilization Improves Closed-Loop Operation*, Vol. 2, No. 12). Figure 2C indicates that a positive phase shift, or phase lead, occurs over a large range of frequencies. This phase lead compensates excessive phase lags originally present in the servo. The maximum phase lead, ϕ_m, is found from the relation:

$$\phi_m = \text{arcsin} = \frac{1-\alpha}{1+\alpha}$$

and occurs at the geometric mean of the two break point frequencies of the transfer function,

$\omega = \frac{1}{\sqrt{\alpha}\,T}$. Here the break frequencies are $\omega_1 = \frac{1}{T}$ and $\omega_2 = \frac{1}{\alpha T}$, and their geometric mean is the square root of the product of the two frequencies.

The foregoing relationships can be grouped for further reference in the design and use of R-C type lead networks. This is shown in Table 2.

The circuit of Figure 2A gives a modified form of error-rate damping. True error-rate damping has a transfer function of the form: $(1+sT)$, as in the numerator of Equation 4. But this true form is modified by the factor $(1 + \alpha sT)$ in the denominator. The denominator term offsets the benefits of the true lead that results from the term in the numerator. Figure 2C shows that the phase lead decreases to zero at the higher frequencies.

The lead network operates on the error signal. However, the attenuation $(\alpha < 1)$ introduced by the network needs increased amplifier gain $(1/\alpha)$.

Another form of dc lead network (Figure 3) uses inductance instead of capacitance, but gives an equivalent transfer function. Here resistor R_2 includes the coil resistance of the inductance.

AC LEAD NETWORKS

The amplitude and phase shift characteristics for an ac lead network (Figure 4) show symmetry around the carrier frequency. There is a similarity between these characteristics for ac and dc lead

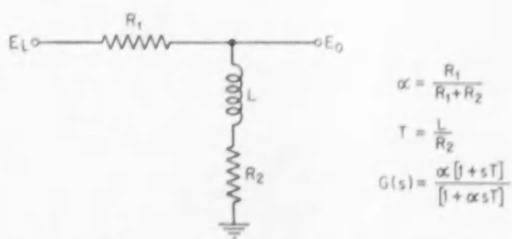
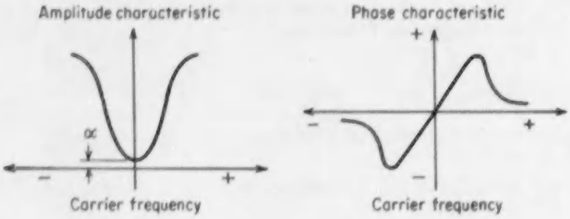


FIG. 3. An alternative circuit uses resistance and inductance to obtain the characteristics required of a lead network.

FIG. 4. The amplitude and phase shift curves of an ac lead network are symmetrical about the carrier frequency, but are similar to the dc lead network.



networks: the characteristics to the right of the carrier frequency in Figure 4 are equivalent to the characteristics in Figures 2B and 2C.

In general, the ac lead network characteristic is similar to a band-pass rejection filter about the carrier frequency. The shape of the amplitude characteristic of Figure 4 led to calling this type of circuit "notch" networks.

There are several ways[1] to develop the characteristics of Figure 4. One is the tuned resonant circuit (Figure 5). The derivation[1] of its transfer function is particularly interesting. At first the analysis includes the carrier frequency, but later this is eliminated because only the modulating frequency (much lower than carrier) is needed to determine stability, as shown on a Nyquist or Bode diagram.

The ratio of output to input voltage (transfer function) of this circuit is:

$$\frac{E_o}{E_i}(j\omega) = \frac{R_2 + j\omega L + \dfrac{1}{j\omega C}}{R_1 + R_2 + j\omega L + \dfrac{1}{j\omega C}} \tag{5}$$

and the final result, in terms of ω_m, the modulating frequency, becomes:

$$\frac{E_o}{E_i}(j\omega_m) = \frac{\alpha\left(1 + \dfrac{2L}{R_2} j\omega_m\right)}{1 + \alpha \dfrac{2L}{R_2} j\omega_m} \tag{6}$$

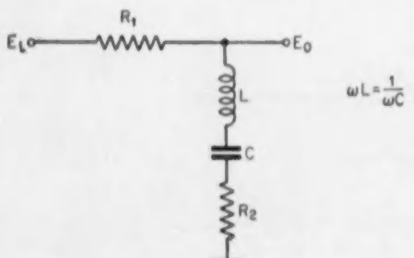


FIG. 5. A tuned resonant lead network typifies one of the many circuits that gives the characteristics of Figure 4.

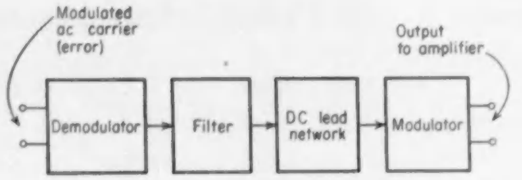


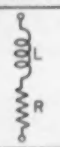
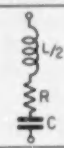
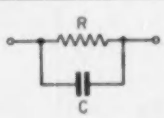
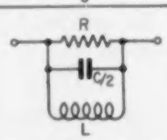
FIG. 6. An ac servo uses a dc lead network by demodulating the modulated ac carrier signal (error signal), passing it through a filter, applying the new signal to the stabilizing network, and then remodulating and amplifying the corrective signal.

Equation 6 shows a similarity to Equation 4. The transfer function of the ac lead network is equivalent to the dc lead network, except that a capacitor tunes the inductance to the carrier frequency and its time constant corresponds to $2L/R$. This equivalence leads to a conversion procedure, as shown in Table 3.

The derivation of the ac lead network transfer function assumes that the carrier frequency coincides with the network center frequency, and that the motor fields are 90 electrical deg apart at the carrier frequency. A variation in these conditions partially destroys the damping properties of the network. Good operation calls for low drift of the carrier frequency and close tolerance on the motor field alignment. Other disadvantages of this circuit: harmonics are emphasized, inductance must be linear, and the inductance pickup of the carrier frequency introduces extraneous effects. However, ac lead networks are practical for many servo applications.

One way to overcome these drawbacks of ac lead networks involves a demodulator-modulator arrangement with a dc lead network. Figure 6 shows a block diagram of the method. Here the modulated ac carrier is first demodulated and then fed to an appropriate filter. The resultant signal, the envelope of the modulated carrier, is acted on by the dc lead network to obtain stabilizing action. Then, the modulator recombines the modified signal with the carrier frequency and sends it to the ac amplifier.

TABLE 3 AC-DC LEAD NETWORK CONVERSION

DC elements	Equivalent AC elements
 L, R	 L/2, R, C; $\omega_c^2 = \frac{2}{LC}$; ω_c = carrier frequency
 R, C	 R, C/2, L; $\omega_c^2 = \frac{2}{LC}$

HOW A NETWORK SOLVES A DAMPING PROBLEM

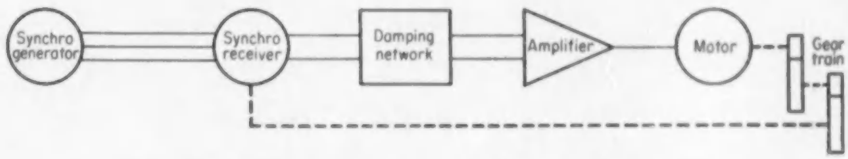


FIG. 7. A repeater-servo illustrates design of a corrective lead network. Although the servo is ac, the damping network is designed on the basis of a dc servo. The dc lead network can be used with a demodulator-modulator arrangement, or converted to an ac lead network.

A synchro-type repeater servo illustrates the network method of improving system performance. The block diagram in Figure 7 shows this type of servo. It is assumed here that all components except the damping network have been designed to meet a given set of specifications:

Carrier frequency	400 cps
Servo natural frequency	20 cps
Servo motor (Kearfott R110)	
rotor inertia	1.13×10^{-3} lb-in^2
stalled torque	1.45 in.-oz
no load (rated) speed	5000 rpm
Load inertia	assumed negligible

THE PROBLEM: evaluate the system without the damping network, and from this information design a suitable corrective network.

The transfer function of the open-loop system is considered as second-order and represented by:

$$G(s) = \frac{A}{s(1 + T_m s)} \qquad (7)$$

where A = the overall open-loop gain constant, and
T_m = the mechanical time constant of the motor

Both of these constants are unknown, and must be derived to determine the frequency response of the uncorrected servo.

The Gain Constant

Consider that the system is in equilibrium and that the motor shaft is twisted to a constant displacement of one radian. The amplifier then exerts a torque on the motor shaft. The magnitude of the torque is found from the relationship:

$$\omega_n = \sqrt{K/J} \qquad (8)$$

where ω_n = the natural frequency of the system ($20 \times 2\pi$ radians)
K = the torque per unit angle (in.-lb/rad)
J = the total inertia referred to the motor shaft (lb-in.^{2})

From the above specifications:
$K = 0.0465$ in.-lb/rad

The overall gain constant is found from this relationship: $A = K/F$

$$\text{where } F = \frac{\text{rated torque}}{\text{rated speed}} = 1.73 \times 10^{-4} \ \frac{\text{in.-lb}}{\text{rad/sec}} \qquad (9)$$

Thus, $A = 269$/sec.

The Time Constant

The time constant equals

$$T_m = J/F = 0.017 \text{ sec}$$

However, the non-linear characteristic of the motor indicates that the time constant for low voltage should be about twice the calculated value, or 0.035 sec. It is advisable to use this higher value.

The Open-Loop Transfer Function

The numercial form of the transfer function becomes, as a result of the preceding analysis:

$$G(s) = \frac{269}{s(1 + j0.035s)} \qquad (11)$$

This corresponds to a break frequency of:

$$f_1 = \frac{1}{2\pi \times 0.035} = 4.6 \text{ cps} \qquad (12)$$

and a magnitude, at this frequency, of:

$$G(f_1) = \frac{269}{2\pi \times 4.6 \times \sqrt{2}} = 6.7 \approx 16.5 \text{ db} \qquad (13)$$

By trial and error, the frequency at unity gain is equal to 13.6 cps; its phase lag is calculated thus:

$$\begin{aligned} \theta &= (90 + \arctan 0.035 \times 2\pi \times 13.6) \text{ deg} \qquad (14) \\ &= (90 + 72) = 162 \text{ deg} \end{aligned}$$

Hence, by definition, the phase margin of the open-loop system without the damping network is

$$\phi = 180 - 162 = 18 \text{ deg} \qquad (15)$$

Optimum performance calls for a phase margin somewhat greater, perhaps 40 to 60 deg.

Lead Network Design

The lead network should give the maximum phase lead at the frequency of unity gain for the overall compensated system. This frequency is determined by trial and error, and is most easily accomplished on a Bode diagram. The amplitude characteristic of the network alone and the amplitude of the system with this network inserted are both plotted. The geometric frequency of the assumed network is shifted until it coincides, roughly, with the frequency at which the overall system has unity gain.

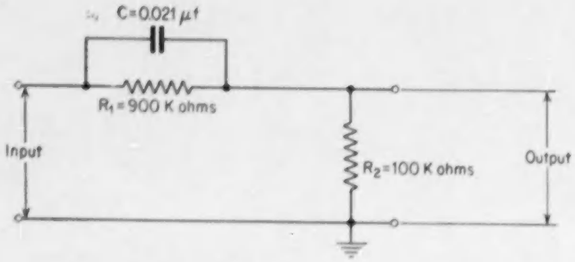


FIG. 8. The analysis of the servo in Figure 7 leads to the above suitable dc lead network, and may be applied with a demodulator and modulator.

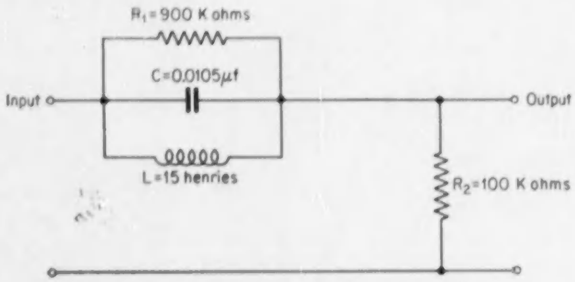


FIG. 9. If the corrective network characteristics for the repeater servo of Figure 7 must be obtained from an ac circuit, Table 3 can be of aid. It facilitates conversion of the dc lead network of Figure 8 to the tuned resonant circuit shown in the above cut.

Using this technique, the low frequency break point of the network for the above system results in about 8.5 cps. Then the time constant becomes:

$$T = \frac{1}{\omega_1} = \frac{1}{2\pi \times 8.5} = 0.0187 \text{ sec} \qquad (16)$$

For these lead networks, an attenuation factor of 0.1 is usually practical; hence, $\alpha = 0.1$. The transfer function of the network to improve the damping of the above servo is given by:

$$G_1(s) = 0.1 \frac{(1 + 0.0187s)}{(1 + 0.00187s)} \qquad (17)$$

But to realize the benefit of the damping network the gain of the servo amplifier must be increased by 10. The overall transfer function of the servo system then is:

$$G(s) = \frac{269}{s(1 + 0.035s)} \frac{(1 + 0.0187s)}{(1 + 0.00187s)} \qquad (18)$$

From a plot of Equation 18 it is found that at a frequency of 23.5 cps the gain is unity, or 0 db. The phase lag at this frequency is equal to:

$$\begin{aligned}\theta &= (90 + \arctan 5.18 + \arctan 0.276 - \arctan 2.76) \text{ deg} \\ &= (90 + 79 + 15 - 70) = 114 \text{ deg}\end{aligned}$$

Hence the phase margin with the lead network is equal to

$$\phi = 180 - 114 = 66 \text{ deg}$$

This represents an increase in phase margin of:

$$\Delta\phi = 66 - 18 = 48 \text{ deg}$$

due to the insertion of the lead network. Thus a significant improvement in the dynamic response and overall stability of the servo has been effected by means of the lead network.

The actual network may now be designed with reference to Figure 2 and Table 2. Assume that the desired minimum input impedance, R_2, is 100,000 ohms. Then:

$$R_1 = R_2\left(\frac{1-\alpha}{\alpha}\right) = 900{,}000 \text{ ohms}$$

$$C_1 = \frac{T}{R_1} = \frac{0.0187}{0.9 \times 10^6} = 0.021 \text{ microfarads}$$

Hence the dc lead network required is as shown in Figure 8.

Because specifications call for an ac carrier type servo, the dc lead network shown in Figure 8 must be used with a modulator-demodulator circuit as indicated in Figure 6. If, however, an ac type network is desired, a design can be effected quickly by means of Table 3. Considering the shunt resonant circuit, the value of inductance is calculated by the following relationship:

$$L = \frac{2}{\omega_c^2 C} = \frac{2}{(400 \times 2\pi)^2 \times 0.021 \times 10^{-6}} = 15 \text{ henries}$$

and the ac carrier-type lead network is that pictured in Figure 9.

Practical application calls for some adjustment in either C or L so that the shunt resonant circuit can be accurately tuned to the carrier frequency. This results in optimum performance. The equivalent response of the ac carrier network only approximates that of the dc network—there may be some noticeable differences in the servo dynamic characteristics between the two systems, especially as the servo bandwidth increases relative to the carrier frequency. This effect is difficult to evaluate, and in most practical cases appears to be either small or negligible.

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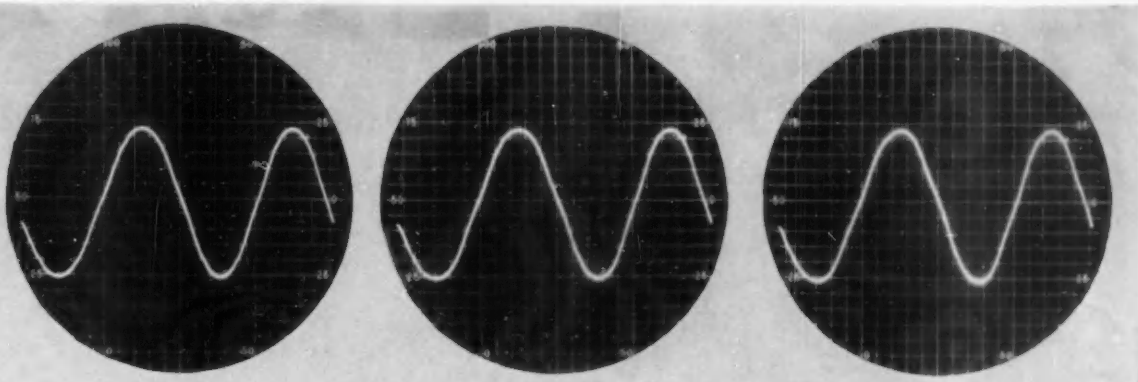

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	Input Volts	Output Volts	3rd	5th	7th
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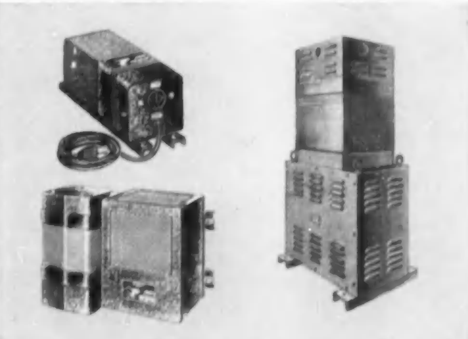
50% Load	115	116.1	1.00	0.70	0.55
No Load	115	116.2	0.65	0.36	0.60

**On production units, the lowest residual harmonic content may occur anywhere between full load and no load.*



TYPICAL MECHANICAL STRUCTURES: The two stabilizers on the left are stock units, the transformer on the right is a "special" in the 7,500va size range.

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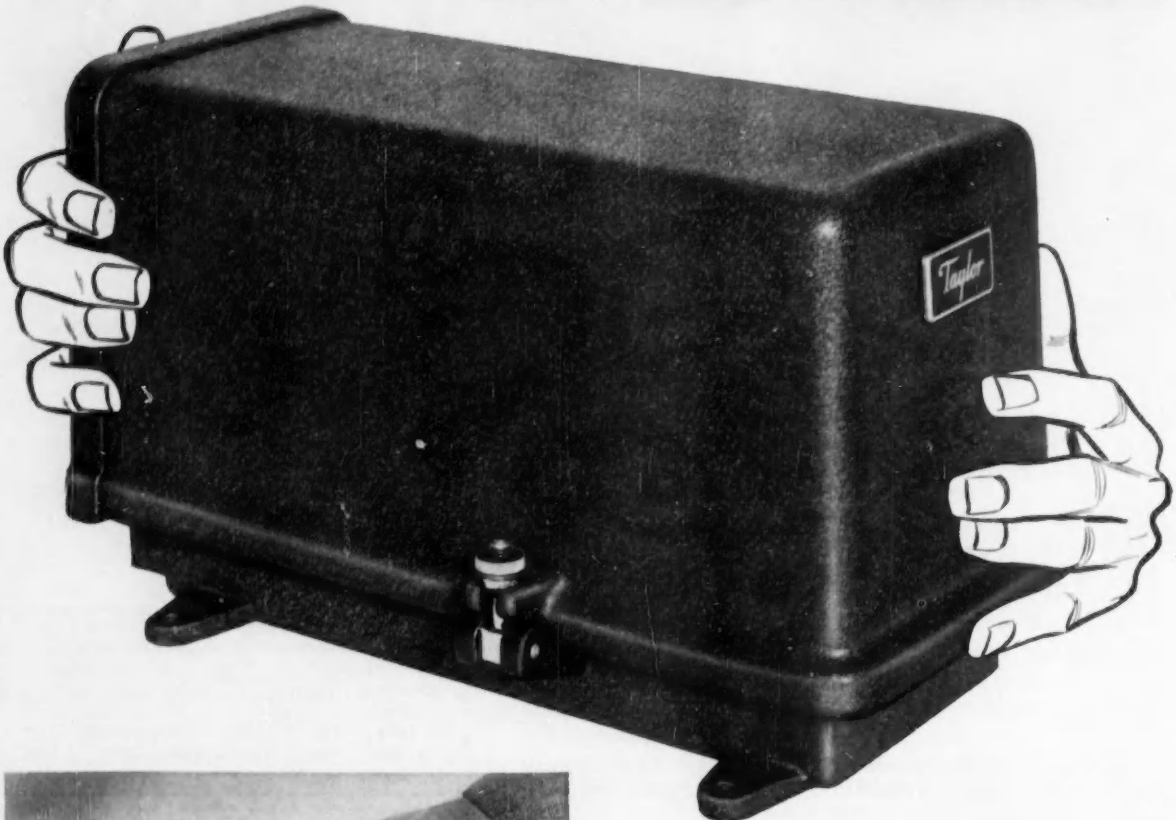

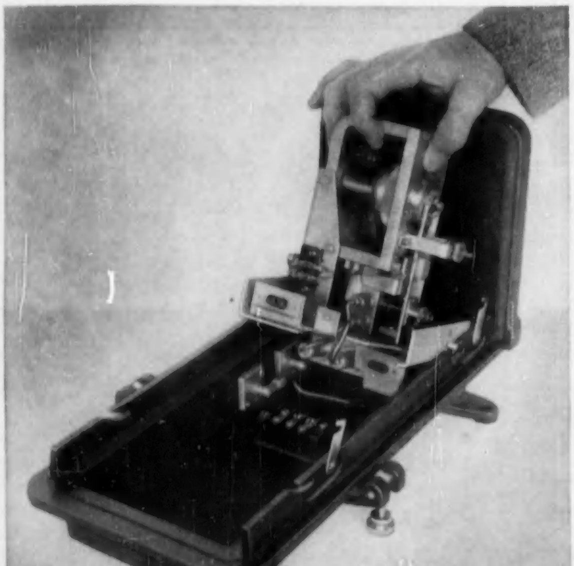

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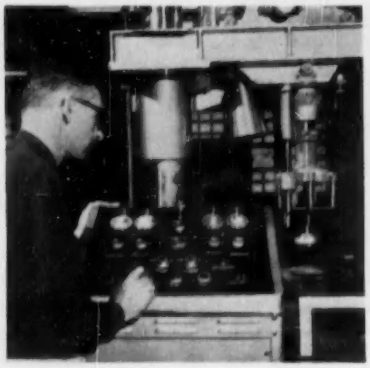
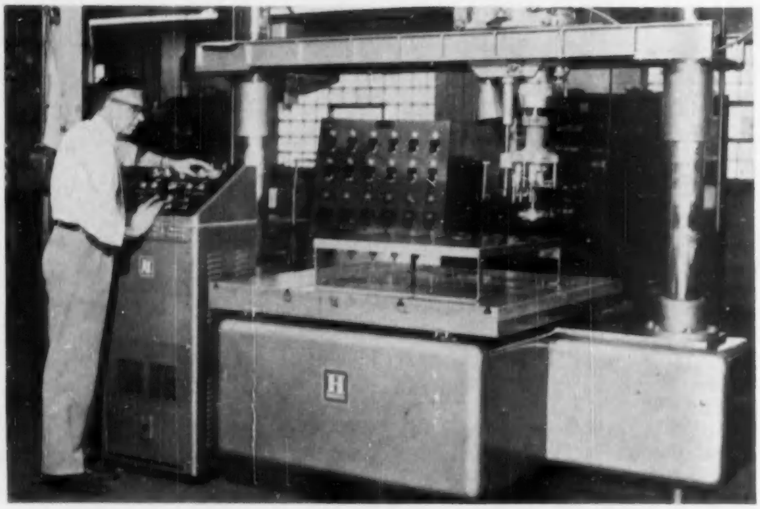
Knob-Controlled Servos Speed and Simplify Panel Drilling

The man at the console below is putting the large traveling drill through some fairly complex hole-cutting routines by merely dialing in coordinates and commands.



The four knobs on top locate workpiece and drill, set hole coordinates. Pushbuttons control sequence, rpm, jog, reset.



The machine, built to design by a St. Paul fabricator, consists of a traveling drill head mounted over a movable table. Its multiple spindle head can drill five holes at one time and cover a 4 ft by 4 ft area. A completed panel is in the background.

JOHN J. RUDOLF
Minneapolis-Honeywell Regulator Co.

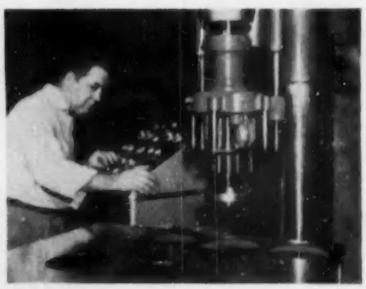
Industrial control panels are usually custom tailored. Hence, cutting various-sized holes for instruments, dials, starters, etc., has necessarily been a tedious manual operation: the layout, checking, center-punching, and drilling of each hole in the ⅛-in. steel sheet consume an average of about 5 min per hole. Further, though hole tolerances are not critical, the process of fashioning a panel is subject to human error every step of the way.

In order to substantially reduce cutting time and the chance for human error, engineers of Minneapolis-Honeywell's Machine Controls Div. have designed an automatic drilling machine that makes cutting holes as easy as tuning a TV set. Starting with a special machine built by Farwell Metal Fabricating Co. of St. Paul, they added automatic controls that enable an operator to "dial" the X and Y coordinates of a desired hole and then drill it by merely pressing a button.

MACHINE DETAILS

Basically, the Honeywell drilling machine consists of a traveling drill head mounted over a movable table. Both table and head can travel 4 ft in perpendicular directions and can thus machine any point in a 4 ft by 4 ft area. Larger panels—8 to 10 ft long and up to 6 ft wide (limited by the throat of the machine)—can be drilled in several steps. The drill spindle travel of 4 in. is adequate for all drilling operations and the entire head and cross rail assembly can be raised or lowered to handle various panel heights.

The machine's drill spindle is driven by a ELC3J thyratron-controlled variable speed motor for optimum spindle speeds for drills as small as 1/32 in. Also, a belt reduction makes it possible to saw or fly-cut large holes up to 6 in. in diam at speeds as low as 3 rpm. The drill head itself is equipped with a multiple spindle attachment that can drill up to five holes simultaneously. For example, the clearance and mounting holes for a pressure gage can be machined in one pass by attaching a hole saw in the center spindle and the required number of small drills in the adjustable spindles. Simultaneous drilling becomes particularly useful when several identical components are to be mounted on a



ONE JOB IT DID

In this typical panel job the large holes were cut with the hole saw (shown) and the three-hole groups were cut in one pass by two drills and a smaller hole saw.

panel. Actually, the idea of using a "memory" to handle duplicated holes with a single spindle was considered first—but was rejected in favor of the far less complex mechanical method.

SYSTEM ACCURACY

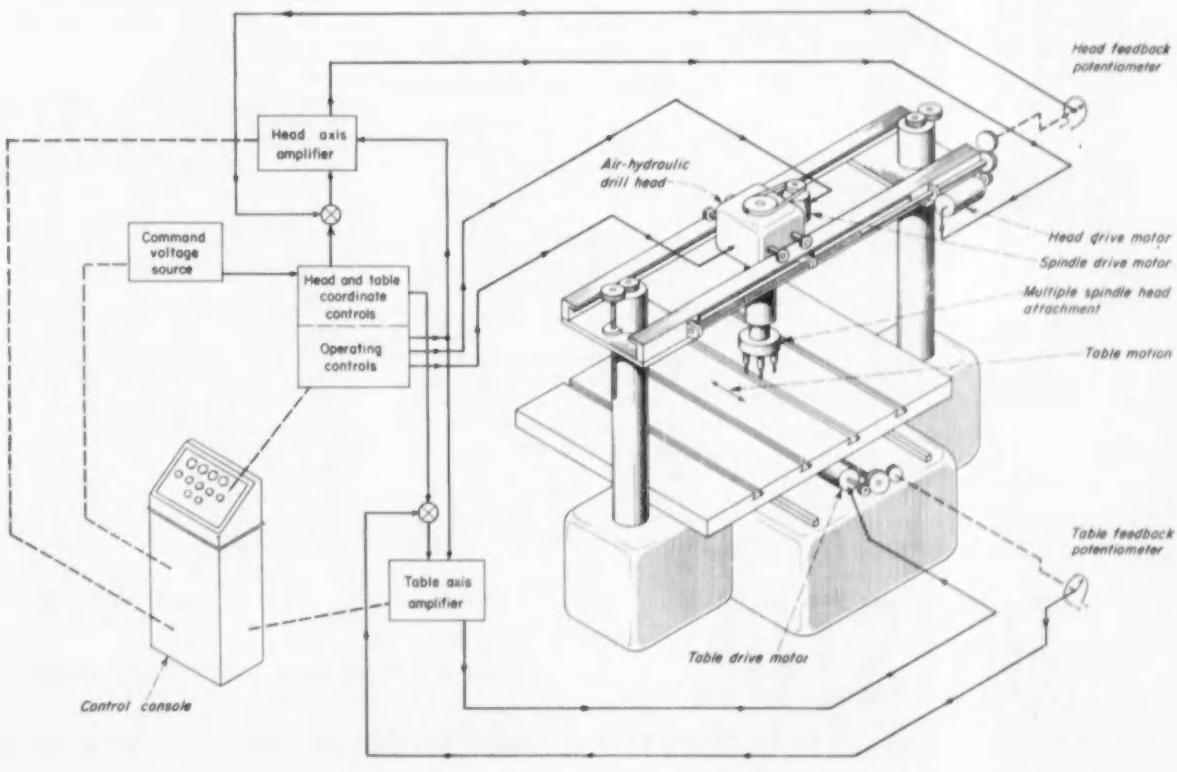
As the control system diagram and its description might indicate, the inherent positional accuracy of the measuring system is not high enough for final hole location since errors are present in the lead screws, feedback potentiometers, and associated gearing. However, a desired over-all accuracy was achieved by calibrating the positioning systems against accurate length bars and adjusting the input voltage dividers to compensate for major nonlinearity errors. The resulting positional accuracy is within a desired 0.005 in. and repetitive accuracy approximately one half of this.

While the locating accuracy of this machine is quite adequate for panel board work, the use of more precise measuring systems would place it into the category of a "poor man's automatic jig borer". If required, punched card or tape control could be readily applied for more automatic operation. Tape or card preparation would be completely straightforward since simple hole coordinates, rather than complex tool paths, form the basis for all machine instructions.

HOW THE DRILLING CONTROL SYSTEM WORKS

In the simplified diagram below, the drill head and table are positioned by conventional positional servomechanisms comprising thyratron amplifiers, ac servo motors, and feedback potentiometers. Inputs to the two servo loops are taken from precision resistive voltage dividers. Voltages from the latter—representing 0 to 48 in. to the nearest 0.001 in.—are knob-selected at the console. The two dc input voltages are compared with their respective feedback voltages, converted to 60 cycle ac signals, and fed into two relay amplifiers. The latter set the desired error thresholds and determine when the servo systems have positioned to within the required tolerance band. The error signals are also channeled to the thyratron power amplifiers, summed with their respective tachometer feedback signals, and used to control the combination ac/dc bias on the thyratron grids. The two servo loops are stabilized by a combination of ac tachometer feedback and error rate compensation in the dc bridge circuits. Dc was chosen for bridge voltage also, to avoid noise and quadrature problems often found in complex ac signal circuits. Additional controls permit jogging all machine motions, selecting spindle rpm, sequencing drilling operations, and choosing constant feed or constant thrust drilling.

In the case of single operations reset controls return the head and work-piece to a location convenient to the operator. Indicator lights show the position of the head and table relative to the called-for position. They allow the operator to pinpoint the location of any reference point on the workpiece with respect to machine coordinates. Hence, the operator does not have to locate the panel accurately on the table; he simply determines where he has placed it in terms of the machine's coordinate system. To do this he jogs the head and table until the spindle is aligned with some reference point on the panel and then adjusts the input selectors until the indicator lights show that the positions called for coincide with those that exist. By correcting all hole coordinate instructions by the amount of these initial settings, he can proceed without aligning the panel.



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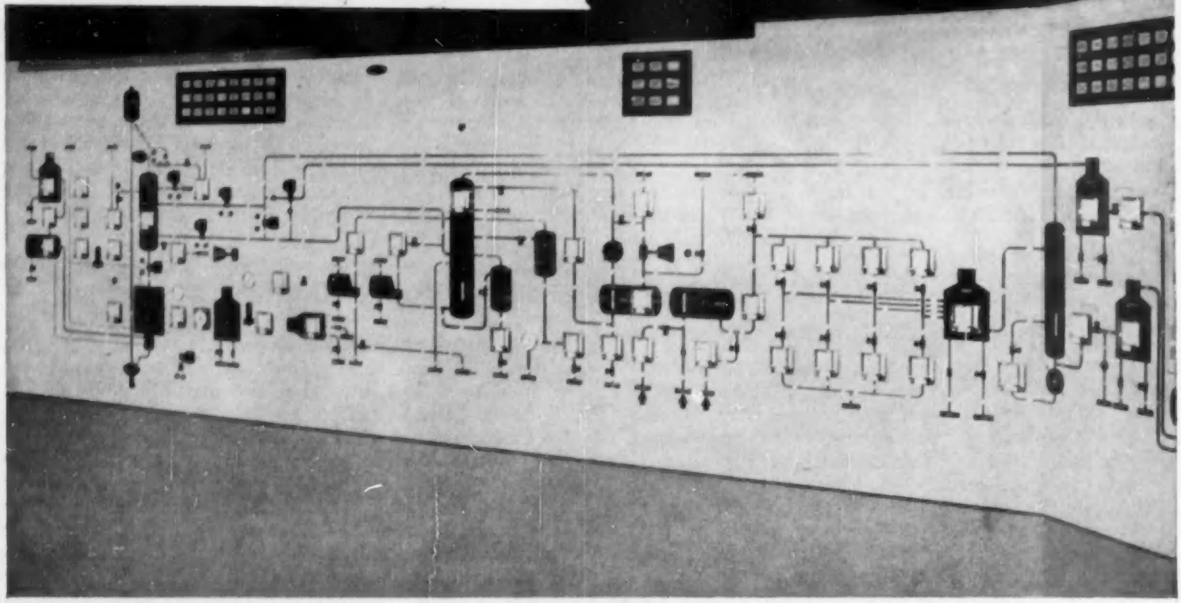

TYPICAL GRAPHIC PANEL of Bristol Metagraphic instruments in oil refinery.

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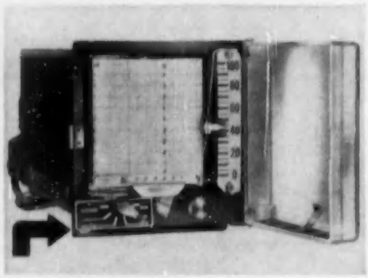
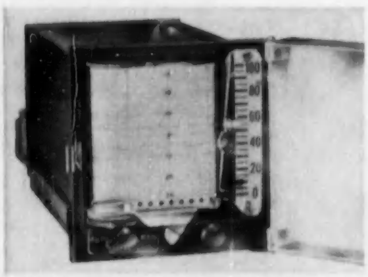


SIX-POSITION TRANSFER VALVE (on one knob) for cascade control.



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AUTOMATIC CONTROLLING, RECORDING AND TELEMETERING INSTRUMENTS

$$= \sqrt{2}\ B \sin \omega_c t\ [A \sin \theta - \frac{A}{n} \sin n\ \theta]$$

The transition from fine to coarse data begins when the peak value of e equals the Zener voltage E_z

$$E_z = \frac{\sqrt{2}\, BA}{n} (n \sin \theta_s - \sin n\theta_s)$$

where θ_s is the switching angle.

The switch from fine to coarse data should be made before the fine data has reached its peak and begins to decrease: 50 deg $< n\theta_s <$ 70 deg. For this value of $n\theta_s$, $(n \sin \theta_s - \sin n\theta_s) \cong 0.25$.

$$E_z \cong \sqrt{2}\ \frac{BA}{4n}$$

The data-speed ratio n depends on particular requirements of the data system. The type of synchro selected fixes the synchro sensitivity B. These two parameters then determine the gain A and Zener voltage E_z of the diodes. Typically, E_z may be any voltage above about 5 v. Gains A that may be expected for E_z in this range will run 10 to 25, readily realized by a single triode voltage amplifier stage.

Figure 3 is a typical switching curve for a 10-speed system with a diode Zener voltage of 5 v. The transition is smooth and the ultimate one-speed gain is the same as in the fine data control zone.

Integrator Computes Tristimulus Values

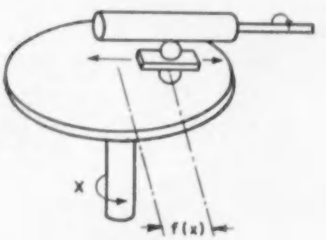


Figure 1

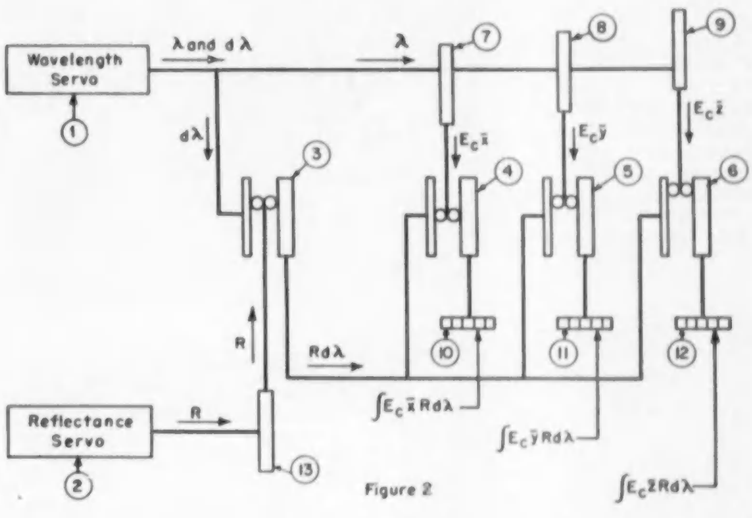


Figure 2

The basic component of the Automatic Tristimulus Integrator is the analog ball and disc integrator, above. At right is the schematic of the ATI's mechanical circuit, which evaluates integrals of the illumination source's spectral distribution.

The measurement of color, like the measurement of other complicated phenomena, lends itself to simplified procedures when the underlying principles are reduced to their basic components. Once the basic components, or tristimulus values, of color are obtained, a unique definition of the color of an object results.

However, each of the tristimulus values requires integration, an operation complicated by the factors inside the integral, themselves functions of wavelength. As pointed out by O. H. Olson in Part I of *Color Basics for the Control Engineer* (CONTROL ENGINEERING, October 1955, page 78) these integrals do not lend themselves to simple evaluation and must be performed graphically or mechanically. The Automatic Tristimulus Integrator (ATI) developed by Librascope, Inc., for use with the GE Recording Spectrophotometer, uses the ball and disc analog integrator to perform the mathematical operations. The integrated values appear on three direct-reading counters.

THE TRISTIMULUS INTEGRALS

The ATI evaluates the following integrals:

$X = \int ExRd\lambda$, $Y = \int EyRd\lambda$, and

$Z = \int EzRd\lambda$

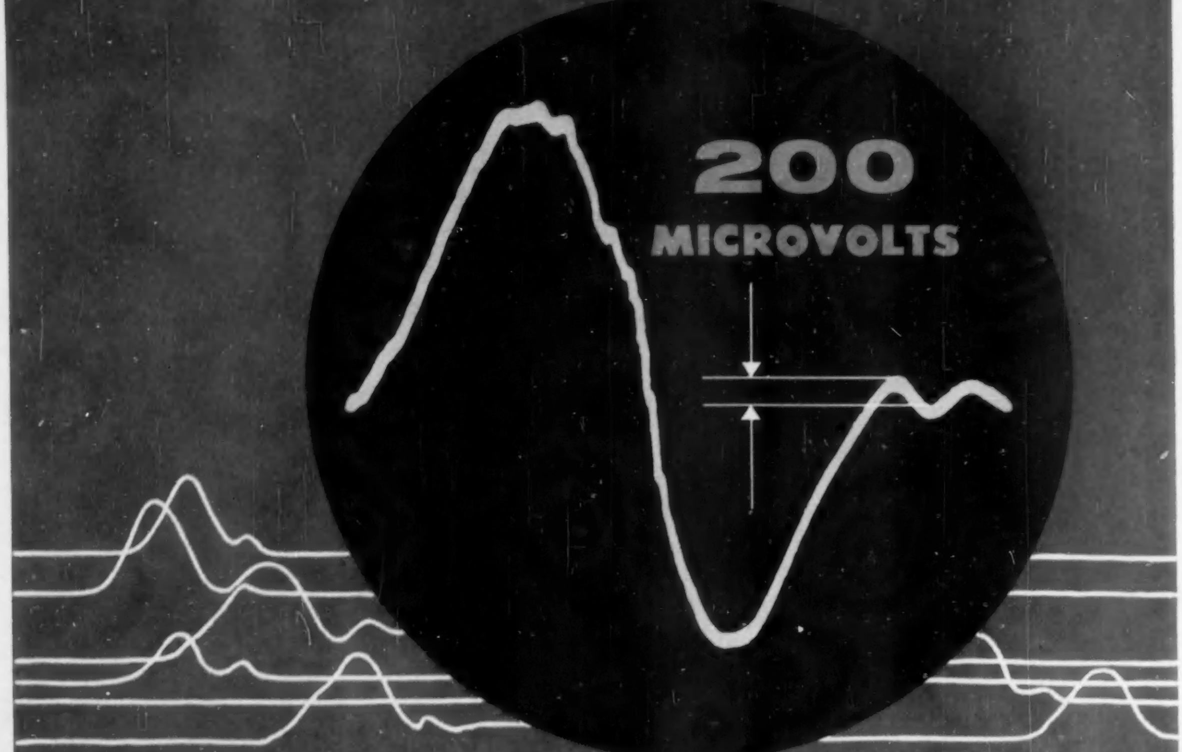
where E represents the spectral distribution of the illumination source, R the spectral reflectance of the colored object, x, y, and z the tristimulus values of the spectral colors, λ the wavelength, and X, Y, and Z the tristimulus values of the colored object under the given illuminant.

BALL AND DISC INTEGRATOR

The basic component of the ATI is the ball and disc integrator, shown in Figure 1. Here is how this computing element works: when the disc of the integrator rotates, it forces the two balls to rotate and they, in turn, rotate the cylinder. The angular rotation of the cylinder shaft is proportional to the product of the distance of the balls from the center of the disc and the angular rotation of the disc shaft. If the rotational displacement of the disc is x and the distance of the balls from the center of the disc is a function of x, $f(x)$, then the device performs integration according to the following relationship:

$$Y = K \int_{x_1}^{x_2} f(x)\, dx$$

where K is a constant of proportionality dependent on the dimensions of the unit, and where the integration



(ACTUAL SIZE PHOTO)

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A Diode's "Zener" Voltage Suits it for Two-speed Data Switching

R. KRAMER, Massachusetts Institute of Technology, and W. R. PORTER, Lieutenant, USN*

* Formerly with MIT's Servo Lab.

The silicon diode's breakdown characteristic can be used in synchro data-switching circuits. Simplicity and smooth constant-gain transition are some values gained.

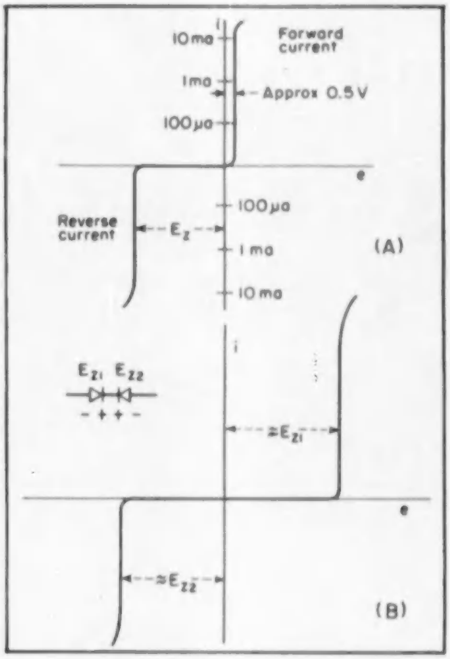

FIG. 1. Typical voltage-current relationship for (A) single silicon junction diode, (B) two back-to-back.

The silicon junction diode is a semi-conductor diode with very high back resistance up to a critical reverse voltage. At this critical "Zener" breakdown voltage, the back resistance drops to a very small value. The Zener voltage is very nearly constant over several decades of reverse current; and it can be controlled during manufacture. At least one manufacturer will supply silicon diodes with the Zener voltage within a small percentage of specified values. Figure 1A shows a typical voltage-current characteristic for a silicon junction diode.

Two silicon diodes in series connected back-to-back have the characteristic shown in Figure 1B. A single diode could be used for switching if the operating point were biased to one-half E_z, but two diodes eliminate the bias problem.

Figure 2 shows the switching circuit. Two data circuits are represented typically by synchro control transformer secondaries with outputs e_1 and e_n for the 1-speed and n-speed circuits. Amplitude B is the synchro maximum output in rms volts.

It is often desirable that the sensitivity at the output of the switching circuit be independent of whichever synchro is controlling. This maintains constant system gain. It may be accomplished by adjusting the gain A and the resistance voltage-divider attenuation to suit the speed ratio n. For small angles the n-speed sensitivity is n times that of the 1-speed; therefore, the amplification should be

$$A = \frac{n}{1 + \dfrac{R_1}{R_2}} = \frac{n}{1 + a}$$

The equality applies for equal gain in the two circuits. The gain can be made greater to produce saturation-slewing into the fine-data control zone.

Where the output of the data-pickoff is a sinusoidal function of position, the voltage e across the diodes (before conduction) is

$$e = \sqrt{2}\, B \sin \omega_c t \left[A \sin \theta - \frac{1}{1+a} \sin n\theta \right]$$

THE SWITCHING CIRCUIT . . . . . . AND ITS PERFORMANCE

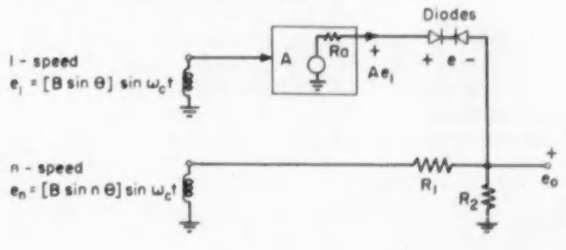

FIG. 2. Circuit for silicon diode data switch has one stage of amplification. Any other method also needs this gain; does not have this simplicity.

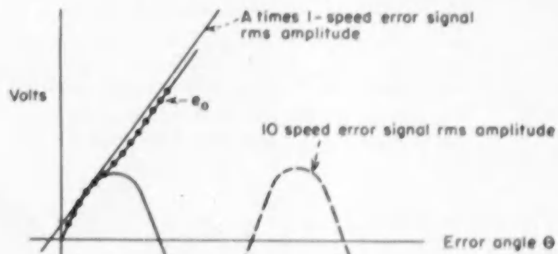

FIG. 3. Switch occurs between 50 and 70 deg on the fine-data synchro. Shown for a Zener voltage of 5 v in a 10-speed system.

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occurs between the limit x_1 and x_2.

OPERATION OF THE ATI

The Tristimulus Integrator receives two signals from the recording spectrophotometer; these signals repeat, through two servo systems, the reflectance and wavelength values produced by the spectrophotometer. Figure 2 shows the schematic diagram of the mechanical circuit of the ATI.

Here, the first integrator unit (3) receives motion from the wavelength servo (1). The balls of this integrator are positioned by the reflectance servo (2) and a cam (13). Thus, the number of turns of the output cylinder of the integrator unit (3) is proportional to the product of the reflectance and the change in wavelength, or $Rd\lambda$.

The parameters E, x, y, and z, are all dependent on the wavelength, but for a given light source the products Ex, Ey, and Ez appearing in the tristimulus integrals can be represented by individual cams profiled to these functions. The wavelength servo positions these cams, (7), (8), and (9). The cams, in turn, position the balls on integrator units (4), (5), and (6).

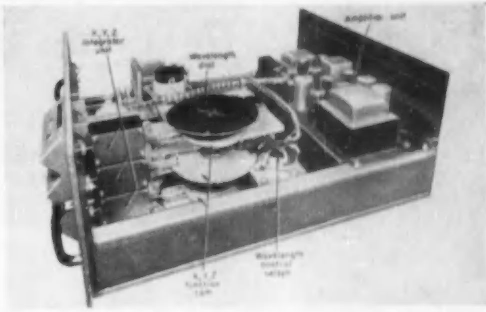


FIG. 3 Assembly of the Automatic Tristimulus Integrator allows easy installation and adjustment, and combines neatly with the recording spectrophotometer (not shown) for which it was designed. The important parts of the device are indicated on the photograph.

$Rd\lambda$, the output of the integrator unit (3), rotates the discs of three other integrators. The number of revolutions of the cylinders of integrator units (4), (5), and (6) must equal $ExRd\lambda$, $EyRd\lambda$, and $EzRd\lambda$. These products are then totaled in the three counters (10), (11), and (12). Thus when the wavelength of the spectrophotometer is varied from 400 to 700 millimicrons, the counters record the value of the three integrals that make up the tristimulus values:

$$X = \int_{400}^{700} ExRd\lambda;$$

$$Y = \int_{400}^{700} EyRd\lambda;$$

$$\text{and } Z = \int_{400}^{700} EzRd\lambda$$

Measuring Small Phase Angles

JACK GILBERT, Norden Laboratories

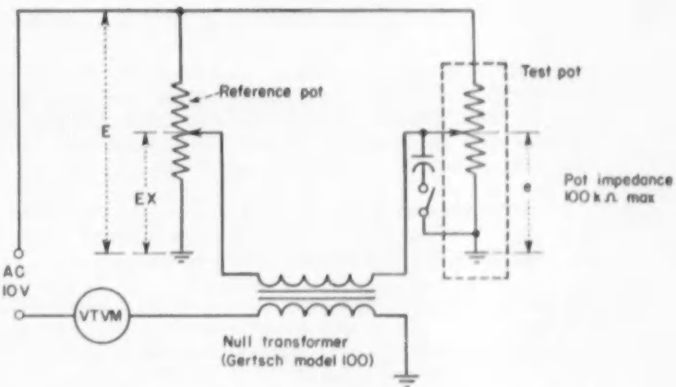


FIG. 1

Phase shift due to potentiometers, precision resistors, computer amplifiers, ac tachometers, and transformer windings can be found by a relatively simple technique that can measure phase angles as small as 0.005 deg and as large as 30 deg. With some loss of accuracy, angles up to 90 deg can also be detected by the method. The detection circuit, with elements of only conventional accuracy, obtains phase shift and quadrature voltage from a reference voltage varying from 50 to 5,000 cps. And the result is accurate to plus or minus 0.01 deg plus or minus 5 per cent at midband (350—1000 cps).

The reference voltage, E, is divided by the reference pot slider until a minimum or null reading is observed on the vacuum tube voltmeter. This voltmeter reading will be the quadrature voltage. The phase shift created by the reference pot is insignificant because of its relatively low impedance and internal construction. Figure 1 illustrates the circuit and Figure 2 its theory of operation.

The voltage ratio X is read directly from the dial of the reference pot, and the null voltage from the meter. An infinite resolution slide-wire type pot is desirable for the reference volt-

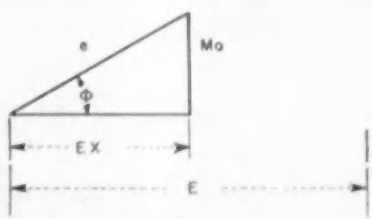
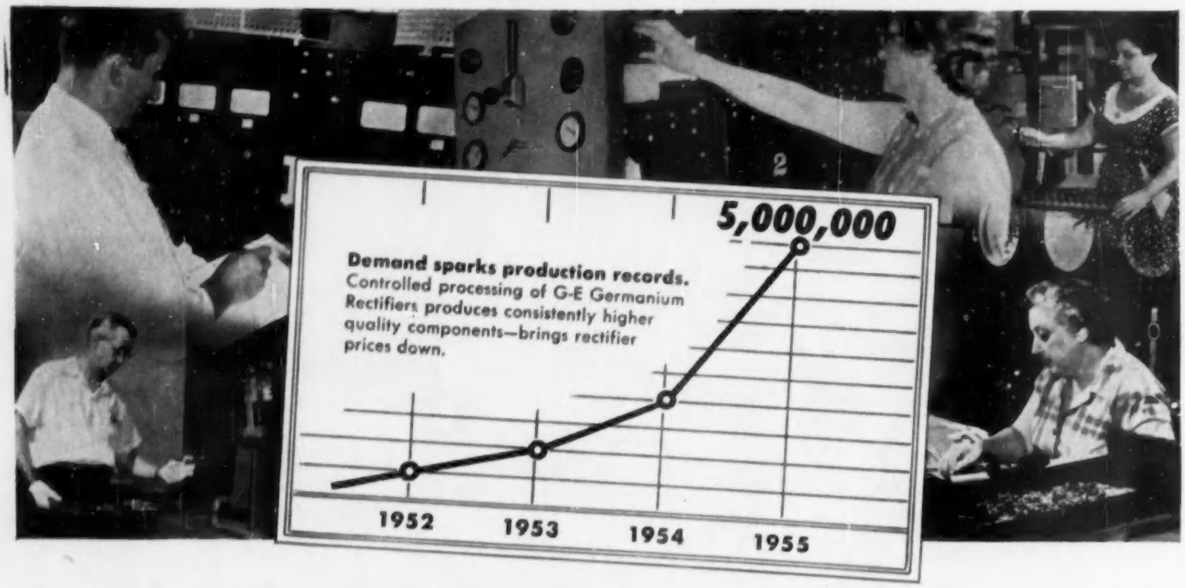


FIG. 2



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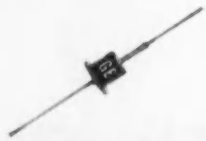
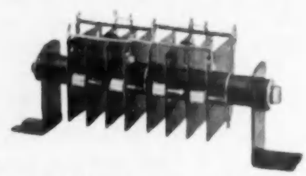
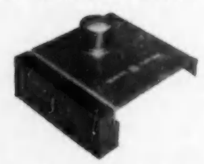


Diffused Junction Germanium Rectifiers combine very high forward conductance with very high back resistance. The high temperature and magnetic amplifier rectifiers feature very low reverse current ratings at ambient temperatures of 85°C.



Power of the basic rectifier unit is boosted 5 times by adding a copper fin. Stacked one to twelve fins in series or parallel, the rectifier may be operated as half wave, full wave, or bridge circuits, and many other types of single or polyphase circuits. Typical power ratings are as high as 3 amps @ 190 volts; 1.3 amps @ 575 volts; 3.6 amps @ 140 volts, etc.



The Medium Power Rectifier has a 5 amp rating at 200 volts (55°C). At 85°C it is rated 2.5 amps at 100 volts. These rectifiers, stacked in series or parallel, have ratings in thousands of watts depending on the design of the circuit.

age divider. The phase shift is an angle whose tangent is equal to Mo/EX. For angles less than 6 deg, multiply the ratio Mo/EX by 57.3 deg to calculate a phase angle within the accuracy of the measurement technique. If a constant reference source is used, the dial of the voltmeter can be calibrated in phase shift directly.

It will be noted that as the phase angle becomes smaller, variations in EX produce an increasingly greater role in the variations of Mo. Hence, the accuracy of the technique for small angles is exceeded by its sensitivity. To achieve the indicated accuracy of 5 per cent, the reference pot should be accurate to ¼ per cent for angles less than 1 deg and the meter calibrated within 3 per cent.

For potentiometers, a small capacitor may be switched across the test component to determine the polarity (lead or lag) of the shift. The change in meter reading is then indicative of the polarity of the phase angle. For instance, if the shift is caused by capacitative reactance of the tested part, the condenser will augment them, increasing the negative phase shift and hence the null voltage. Similar techniques may be used for other components.

A plot of the phase shift of an unloaded ten-turn potentiometer can be easily calculated once its time constant is known. The time constant could be found by suitable calculation involving the phase shift measurements (obtainable by the balancing technique), but here is a direct way of finding it.

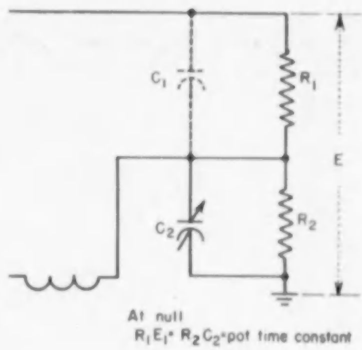


FIG. 3.

Figure 3 shows the setup. R_1 is the entire ten-turn pot. R_1C_1 is the time constant produced by the distributed capacity of the pot. C_2 is a variable capacitor, and R_2 a small fixed resistor of approximately the same resistance as the pot. The phase shift through this resistor is too small to be significant. Only when the adjustable capacitor, C_2, is such that R_2C_2 equals R_1C_1 is the output voltage in phase with the input voltage. With the reference pot set near its halfway point, the in-phase component of the voltage e will equal the voltage EX, but will be out of phase with EX depending on the time constant of R_1C_1.

This time constant can now be used in the following equation to find the quadrature voltage of any of the ten-turn pot's shaft settings.

$Mo = E\omega RC\,(1-2S)\,(1-S)\,(S)$

E = input voltage

ω = radian frequency

R = potentiometer overall resistance

C = equivalent lumped capacity measured across end terminals

S = shaft position, in per cent of maximum rotation.

Similarly, one can calculate phase shift (in radians) by

$\phi = \omega RC\,(1-2S)\,(1-S)$

Since similar expressions can be derived for other pot types, one reading provides all the information needed to plot a pot's phase shift characteristics.

Rather than a slide-wire pot, an ideal standard voltage divider is a Gertsch Ratio Standard, Model PT-5. Resolution better than 0.001 per cent is available together with a voltage ratio accurate to within 0.004 per cent. The advantage of this item is accurate output with very low internal impedance and extremely low phase shift.

Magnetics Sleuth a Hidden Valve

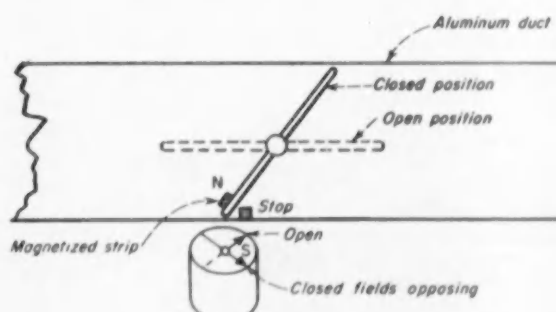
EDWARD S. SHEPARD, SR., AiResearch Mfg. Co.

The problem at AiResearch was to monitor the angular position of a butterfly valve, which operated inside a round aluminum duct. Engineers solved the problem by magnetizing the valve and following its movement with a magnetic compass, directly under it on the outside of the duct. Here's the way they did it:

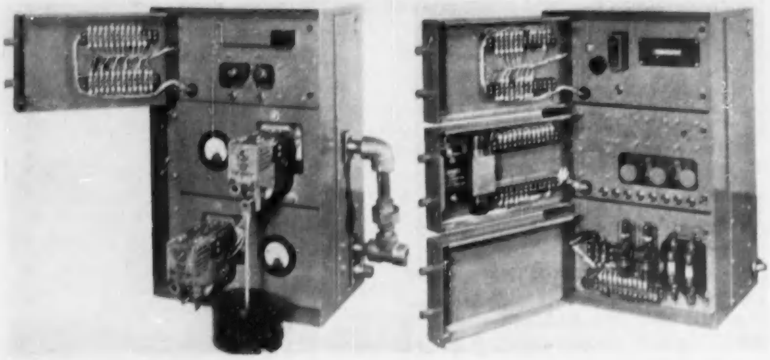
The butterfly valve, a simple air-operated damper, did its job under rather high air velocity and air pressure. Two stipulations concerning the monitoring method were that no holes were to be made in the damper, and nothing was to be attached to it that could not be removed after the tests were completed. Only one method seemed possible under these conditions and it turned out to be the simplest.

A tiny magnetic strip (it could have been a pellet as well) was fastened to an edge of the valve by strain-gage cement. The resulting increase in the thickness of the valve at that point, less than ⅛ in., represented negligible air resistance.

The magnetic compass mounted on the outside of the duct was a fluid-damped device of high quality. In the illustration, the valve is in the closed position and the compass is oriented so that its deflection is at a maximum. As the valve is moved from the closed position the compass needle will follow through a 90 deg excursion, at the end of which the valve will be fully open.



NEW PRODUCTS



LISTING IN GROUPS

ALL ELECTRONIC tubeless circuit for high speed, multi-variable flow computer.

Accepted method of measuring gas flow in large quantities involves the measurement of a differential pressure across an orifice plate. However, the differential pressure itself is not a direct or accurate indicator of flow. Involved in the accurate measurement of flow by differential pressure is the absolute static pressure, the temperature base, the specific gravity, the flowing temperature, the Reynolds number, the expansion factor, and the supercompressibility. Some of these factors vary rapidly, some slowly, some remain constant in given installations.

A variety of pneumatic, mechanical, and manually operated devices have been designed to more or less automatically make the required computation. Now comes the electronic method, represented by the ingenious device depicted by the block diagram. With the advent of accurate pressure-to-voltage transducers, it has become possible to develop such electronic flow calculators, and one of their advantages, the maker of the present device says, is the possibility that electrical outputs without computation lags can be used as control voltages. Other advantages: the ability to indicate and record with conventional electrical instruments, and the possibility of high frequency response within the computer. The latter enables exact computation during rapid fluctuations of the measured pressure.

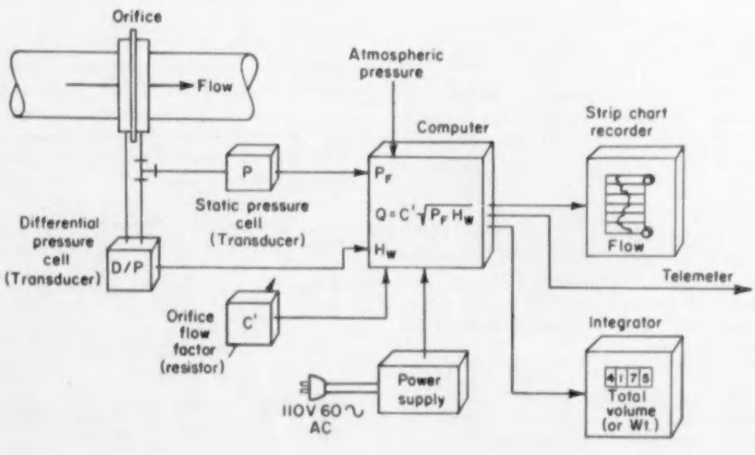
The importance of this last feature, it is said, becomes apparent when one realizes that the basic equation for the computation of flow involves the square root of the differential pressure. Hence, the flow that might occur for the steady average value of a fluctuating pressure signal is not equal to the flow that might occur during fluctuations around this figure. An instrument incapable of following these fluctuations would tend to present the average value for flow computation, which, as mentioned, differs from the flow resulting from the fluctuating pressure itself.

Since the ideal location for many flow meters is immediately after a pump, the magnitude of the pulsations in a gas line can be quite substantial. Also, flow fluctuations can be increased due to phasic effects of various pulsations in a given system.

The flow computer shown above is free of vacuum tubes and yet completely electronic. Its design, says the maker, was made possible only since the advent of pressure-to-voltage transducers, high gain magnetic amplifier computing circuits, and reliable semiconductors, all just recently available. The resulting system is said to perform with an accuracy at the output of 1 per cent. The actual computing portion of the system operates with an accuracy of 0.01 per cent, but the indicating devices are unable to match this tolerance. Flow fluctuations as high as 500 cycles per minute are followed by the system.

An advantage of the completely electronic design, the maker adds, is the relative ease of introducing various independent variables into the computation from conventional electrical pickups. *Southwestern Industrial Electronics Co., Houston, Tex.*

Circle No. 1 on reply card



MECHANICAL flow computer integrates product of square roots.

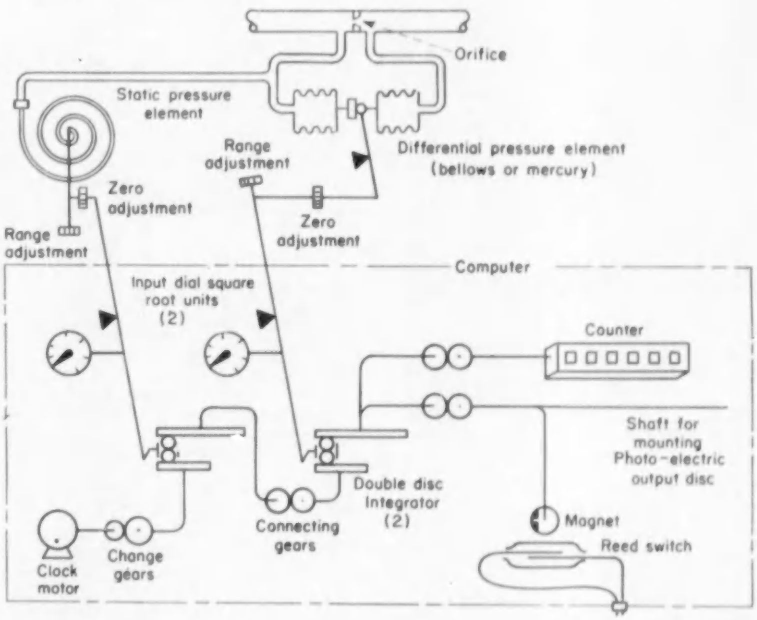
In describing the flow computer on the opposite page, some mention was made of the basic problem involved in measuring flow from a differential pressure indication. Where the object of a flow measurement is the integration of its rate for the purpose of indicating the total volume of material transmitted, the instrument shown here does the job through an ingenious mechanism in a compact package.

A pneumatically or electrically driven clock motor provides the basic power source for the flow integrator, continuously computes the extension factor in the flow equation; that is, the square root of the product of static and differential pressure. The result is shown on a counter-like display.

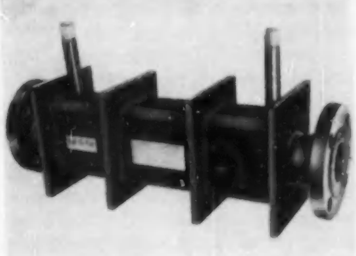
The figure at the lower left shows how conventional pressure element inputs are used to control the operation of two unique square root deriving double-ball-and disc type integrators connected in series. They place an extremely small load on the pressure elements. The integrators are used here as speed changers, multiplying the output of the clock motor by the square root of static pressure and the square root of the differential pressure. This produces the required function. A dial indication of the static and differential pressures utilizes square root calibration to provide a direct reading of these values from the sensing bellows.

A standard electric clock motor provides enough torque to total 18,000 counts per hour. An optional feature is a magnet-operated reed switch, which can provide a pulse rate output to operate a remote electro-mechanical counter. *Libroscope, Inc., 808 Western Ave., Glendale, Calif.*

Circle No. 2 on reply card



SENSORS AND DETECTORS

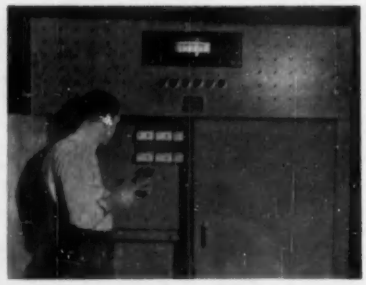


GAS LOW creates linear differential pressure.

This gas flow measuring device (left) indicates flow linearly when used with differential pressure pickups. It operates on the principle of the linear pressure drop set up by the viscous flow of fluids in thin channels. It accomplishes this effect by providing a number of flow channels in which the Reynolds number is kept below 400 at full scale flow. Pressure taps permit manometer or differential pressure gage sensing. The linearity of the element assures true average flow indication despite pulsating flow input. Further advantages are low pressure drop, accuracy down to zero flow, and reliability of a static element. Standard flow ranges are from 0.003 cfm to 100 cfm for steam and most of the common gases, at pressures from 1 in. Hg absolute to 2,000 psig. *National Instrument Laboratories, Inc., 6108 Rhode Island Ave., Riverdale, Md.*

Circle No. 3 on reply card

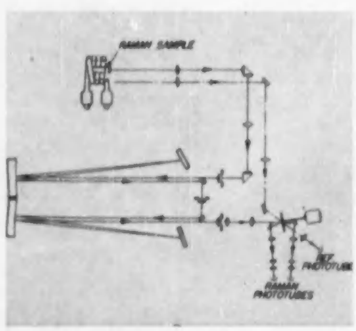
NEW PRODUCTS



SEVENTY-TWO points scanned and controlled.

Up to 72 temperature-sensed stations are scanned and controlled within 4 minutes by this new Control Center. Thermistors are used as sensing elements and the control units provide dual SPDT switch action with a spread between setting indexes from 0 to 10 per cent of the entire scale. Push button selection of any one of the monitored points is possible, with visual and audible alarm for "off limits" conditions. *Wheelco Instruments Div., Barber-Colman Co., Rockford, Ill.*

Circle No. 4 on reply card



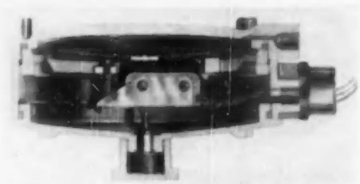
RAMAN spectrophotometer shows tiny samples.

The impressive optical system above is the heart of a new Raman Spectrophotometer, Cary Model 81, described as particularly useful for small samples and quick analysis. With the Model 81 a complete Raman spectrum of benzene can be made in 5 min with as little as 0.1 milliliters of sample. Because water and other polar compounds exhibit weak Raman spectra, they are suitable for use as solvents in Raman spectroscopy. *Applied Physics Corp., 362 W. Colorado St., Pasadena 1, Calif.*

Circle No. 5 on reply card

VIBRATION MONITOR: A new, explosion-proof device operates on the theory that with rotating equipment an increase in vibration bodes ill. It closes circuits carrying up to 5 amp to signal the fact. *The Beta Corp., Forest Ave., at Ridge Road, Richmond 26, Va.*

Circle No. 6 on reply card



HALF-INCH WATER pressure change operates switch.

This externally adjusted switch reacts when a liquid or gas pressure rises or falls to a value of 0.5 in. of water. It requires air or inert gas as its reference pressure. The setpoint can vary from 0 to 45 in. of water. *Barksdale Valves, 5125 Alcoa Ave., Los Angeles 58, Calif.*

Circle No. 7 on reply card

EXTENDED RANGE FLOWMETER: A flowmeter intended for engine test applications, hydraulic test work, and as a flow standard for calibrating flow metering equipment features automatic correction for changes in density of the metered fluid through variations of specific gravity from 0.6 to 0.9.

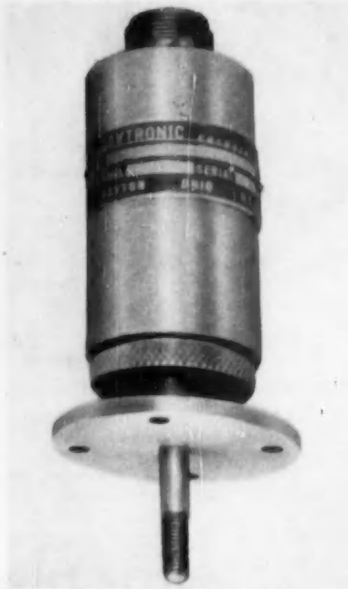
The specific gravity sensing element consists of a precision potentiometer rotated by the fluid flow. Its voltage output influences the ac to dc converter used with the ac output flow sensor. The device is accurate to within ½ per cent full scale. By automatically switching to new flow sensing elements as flow demands require, five ranges are provided for a full flow range of 30,000 to 1 or more. *Potter Aeronautical Co., Route #22, Union, N. J.*

Circle No. 8 on reply card

HIGH TEMP COUPLE: For use in temperature up to 1800 deg C is a new thermocouple that features platinum 30 per cent rhodium to platinum 6 per cent rhodium calibration. It achieves its high-range performance without sacrificing either corrosion re-

sistance or sensitivity. *Thermo Electric Co., Inc., Saddle River Township, Rochelle Park P. O., N. J.*

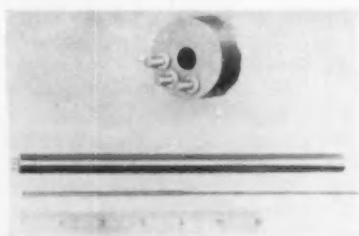
Circle No. 9 on reply card



MOTION TRANSDUCER sensitive to a millionth of an inch.

Motions as little as one millionth of an inch to as large as 0.124 in. are detected by the Model 100 Universal Displacement Transmitter. A micrometer zero adjust permits mechanical and electrical zero to be adjusted after installation. Sensitivity is 5 millivolts per 0.001 in. with 6.3 v, 60 cps ac excitation. Output impedance is 200 ohms, linearity to ½ per cent. *Dyatronic Corp., 216 S. Main St., Dayton 2, Ohio*

Circle No. 10 on reply card

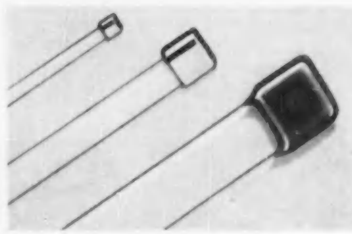


POSITION PICKUP insensitive to high temperatures.

This linear motion transducer operates on the principle of variable permeance as part of an ac bridge. It mounts in a ½ in. hole and withstands temperatures as high as 1,300 deg F.

The body exposes only stainless steel and is designed for use in furnaces, reactors, etc., where it will measure motion up to 4 in. and down to 0.2 in. Resolution of better than 0.000,000,1 in. and linearity from 1.5 to 0.3 per cent are claimed for all models. Operating sensitivities are from 0.1 to 3 v per in. *Crescent Engineering & Research Co., 11632 McBean St., El Monte, Calif.*

Circle No. 11 on reply card

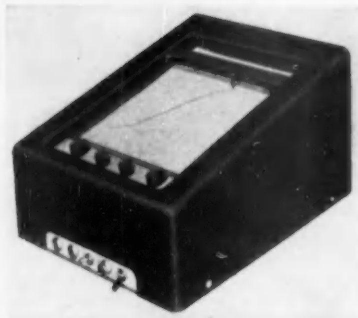


WAFER-LIKE thermistors available without delay.

Seen above are a few examples of a complete new line of wafer-sized thermistors. The new elements are stocked in resistances ranging from ohms to megohms, and with temperatures coefficients as high as 7 per cent per deg C. The maker says the sample quantities in any resistance value are available without delay. *Gulton Industries, Inc., Metuchen, N. J.*

Circle No. 12 on reply card

INDICATORS AND TESTERS

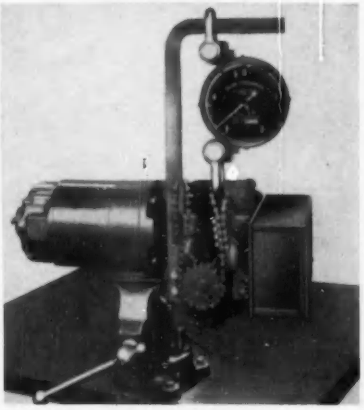


FLAT BED PLOTTER features high speed response.

The X-Y recorder shown above uses 8½-by-11-in. chart paper for flat bed presentation. Full scale pen speed is ½ sec. Eleven scale ranges run from

5 millivolts to 500 v full scale. Input impedance is 200,000 ohms per volt. *Electro Instruments, Inc., 3794 Rosecrans, San Diego 10, Calif.*

Circle No. 13 on reply card



SIMPLE RIG for measuring static torque of motors.

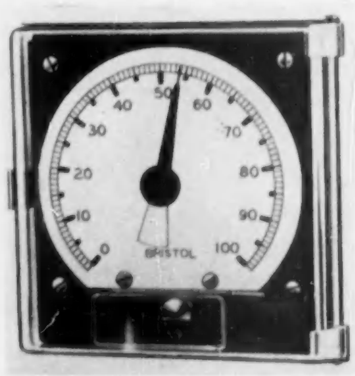
These Dillon people are loaded with interesting applications for their dynometer. The photo above shows how you can measure the static torque of a motor with a minimum of bother. *W. C. Dillon & Co., Inc., 14620 Keswick St., Van Nuys, Calif.*

Circle No. 14 on reply card

VACUUM-TUBE voltmeter measures pulse height.

The instrument above has the unique function of measuring the amplitude of pulses regardless of their widths. Accuracy is to within 2 per cent full scale and readings are independent of widths of from 0.01 microsec upward. Ranges of 0 to 10, 30, and 100 v are offered. The PV-812 Pulse Height Vacuum-Tube Voltmeter is provided with a 5-in. meter and knife-edge point and mirror scale. *Television Accessories Co., 1412 Great Northern Bldg., Chicago 4, Ill.*

Circle No. 15 on reply card



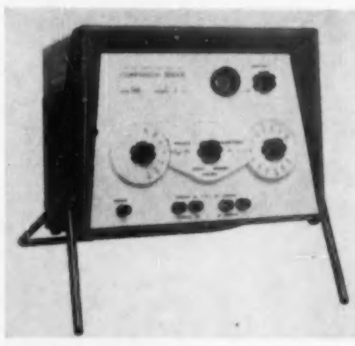
TELEMETER receiver designed for panel mounting.

The indicator above, identical in appearance to the company's line of pneumatic signal indicators, uses the pulse-width information signals of Bristol's Metameter telemetering system. Strip-chart recorders as well as dial indicators come in the 5-in. sq size *The Bristol Co., Waterbury 20, Conn.*

Circle No. 16 on reply card

ELECTRONIC BALANCING MACHINE: A machine identified as Type 1250 dynamically balances high speed rotating elements at speeds up to 2,700 rpm by detecting out-of-balance masses as low as 0.0013 per cent. A stroboscoptic light is controlled to locate the unbalancing mass. *Hickok Electrical Instrument Co., 10589 Dupont Ave., Cleveland 8, Ohio.*

Circle No. 17 on reply card



A COMPARISON BRIDGE for phase shift, reactance.

Here's styling for you, wrought iron and all. It's a comparison bridge for measuring the reactance, impedance, and phase shift caused by resistive, and capacitive components. Accuracy to within 0.01 per cent is

NIXIE

Newest STAR IN THE ELECTRONIC GALAXY

SOME TYPICAL NIXIE APPLICATIONS

1. DIGITAL VOLTMETERS
2. COUNTERS
3. CALCULATORS
4. ALTIMETERS
5. RADAR
6. DIAL SYSTEMS
7. REMOTE POSITION INDICATORS

Haydu's 10 digit in-line numerical indicator!

Small, electronic indicating tube uses the direct read-out method which clearly displays the digits at top surface of tube. This method assures the highest readability from a wide angle . . . speeds work, reduces errors, cuts costs in hundreds of diversified applications.

NOTE THESE OUTSTANDING ADVANTAGES:

- Small, simple plug-in tube
- Uses standard sockets
- Vivid numbers for highest visibility
- Low power required
- Operates directly off Beam Switching Tubes or any voltage source
- Radical Simplification of circuitry
- Long life
- Rugged construction

HB 106

Write to Haydu Tube Division, Dept. 10, Plainfield, N. J., for complete information on your applications.

HAYDU

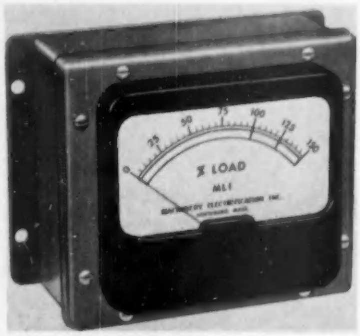
BROTHERS OF NEW JERSEY

PLAINFIELD, NEW JERSEY

SUBSIDIARY OF BURROUGHS CORPORATION

claimed. The resistance range goes to 20 megohms. It contains a two-stage detector and an oscillator, enabling operation between 100 cycles and 10 kilocycles with suitable plug-in networks. Null indications are provided by an electronic eye. *Electro-Measurements, Inc., 4312 S. E. Stark St., Portland 15, Ore.*

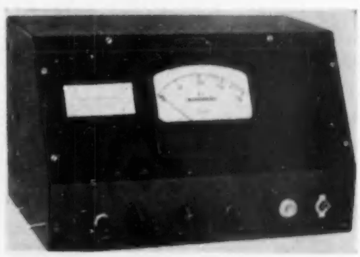
Circle No. 18 on reply card



MOTOR LOAD directly shown as per cent of maximum.

This indicator, calibrated in percentage of motor load, does a more direct job when used with machine tools than the conventional ammeter. The highly damped instrument eliminates needle waver due to vibration or minor load changes. Dual voltage units are adjustable for operation on either 220 or 440 v systems. *Machinery Electrification, Inc., Dept. SRR, Northboro, Mass.*

Circle No. 19 on reply card



SPECTROSCOPIC analysis with simple instrument.

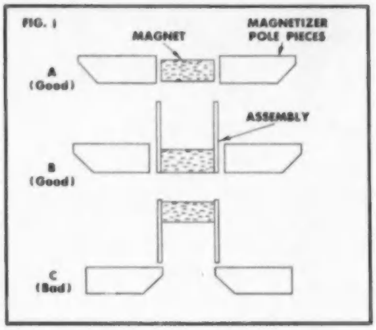
Spectroscopic analysis of gaseous or chemical constituents by emission, transmission, or absorption can be performed by non-technical personnel with the simple dial and meter arrangement shown above. Narrow-band infrared, ultra-violet, or visible filters can be handled. Axler Associates, Inc., 102-42 43rd Ave., Corona, N. Y.

Circle No. 20 on reply card

INDIANA
PERMANENT MAGNET
DESIGN INFORMATION

published for industrial and consumer product engineers and designers

HOW TO MAGNETIZE PERMANENT MAGNETS



Magnetizing permanent magnets after assembly into the product offers several advantages. Higher field strengths are obtainable. The magnetic field produced in a loudspeaker, for example, using an Alnico V permanent magnet that has been magnetized after assembly, is about three times as great as the field obtained when the same magnet is magnetized before assembly.

The unmagnetized magnets are easier to handle and to assemble with other parts of the assembly. There is less contamination due to pick-up of magnetic particles.

Magnetizing after assembly is also advantageous in such applications as watt hour meters, polarized relays, and permanent magnet motors.

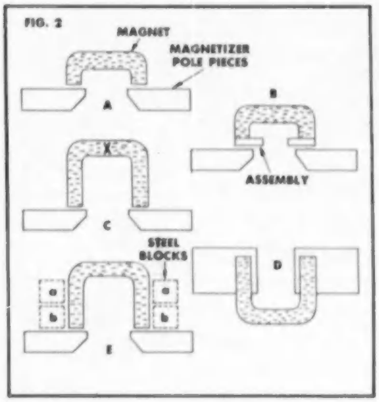
Using the Magnetizer

Most commonly used magnets are of simple bar or "U" shapes, which may be magnetized with an electromagnetic magnetizer in the user's plant.

Fig. 1-A shows how a bar magnet should be positioned between the magnetizer's pole pieces. The square ends of the pole pieces are used toward the gap. The space between the pole pieces is adjusted so the magnet can be easily inserted and removed. Normally, only one to two seconds are required to fully magnetize the magnet.

An assembly consisting of a bar-type magnet and soft-steel pole pieces should be placed with the magnet between the magnetizer pole pieces as shown in Fig. 1-B. Positioning the assembly as shown in Fig. 1-C will not fully saturate the magnet.

"U" shaped magnets and assemblies should be positioned as shown in Fig. 2, with the tapered ends of the magnetizer pole pieces used toward the gap. A meter or separator assembly would be placed on the magnetizer as shown in Fig. 2-B.



When a "U" shaped magnet is tall or larger than the generally accepted setting of the magnetizer, the field produced at point "X" (see Fig. 2-C) may not be sufficient to saturate the magnet. In this case there are two acceptable methods of magnetization. One is to place the magnet with its side on the pole pieces as shown in Fig. 2-D. This allows the yoke of the magnet to become magnetized. The magnet is then raised to the position in Fig. 2-C and again magnetized.

The other procedure is to stand the magnet on the magnetizer pole pieces with one or two steel blocks against each of its legs as shown in Fig. 2-E. The magnet (or assembly) is then magnetized three times: first, with both pairs of blocks in place; second, with blocks (a) removed; and third, with blocks (b) also removed.

For a complete discussion of how to magnetize permanent magnets by the electro-magnetic method, write for a copy of *Applied Magnetics*, Vol. 2, No. 3.

Chesterfield?

Cigarette manufacturers invest a great deal of time and money to bring you the best smoke possible.

Chesterfield is no exception . . and strangely enough, behind some of their recent efforts is an Indiana Permanent Magnet. You've probably read dozens of ads which say, "Chesterfield . . made the modern way . . with AccuRay."

AccuRay is a machine, made by Industrial Nucleonics Corp., that checks and controls the making of Chesterfields. One of the basic parts of this machine is a contact meter-relay, manufactured by Assembly Products, Inc. And the heart of this relay is an Indiana Hyflux Alnico V magnet!

Report on Indox I Ceramic Permanent Magnets

This recently published four-page technical bulletin, "Indox I Ceramic Permanent Magnets," suggests factors to be considered during design calculations, and discusses possibilities for new applications or improvements of existing ones.

Also discussed are some 30 representative sizes and shapes available in sample quantities for immediate shipment. Ask for price list and Catalog 15-P-1.

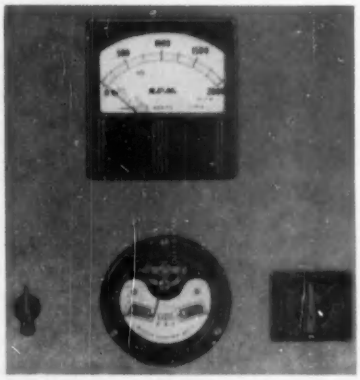
THE INDIANA STEEL PRODUCTS COMPANY
Valparaiso, Indiana
WORLD'S LARGEST MANUFACTURER OF PERMANENT MAGNETS

INDIANA
PERMANENT
MAGNETS

MICROSEC DELAYS accurately generated.

Duration of waveforms, pulse widths, delay characteristics of oscillograph amplifiers, and other time-basis functions can be measured with the aid of the time delay generator shown above. The Type 326 has three overlapping ranges from 1.5 microsec to 10,000 microsec. Low impedance of trigger output minimizes loading effect of equipment triggered. Its output is two pulses, one delayed. The delayed output triggering pulse has a 50 v minimum and a rise time of 0.15 microsec with a width, at 50 per cent of maximum, of 0.5 microsec. *Allen B. Du Mont Laboratories, Inc., 750 Bloomfield Ave., Clifton, N. J.*

Circle No. 21 on reply card

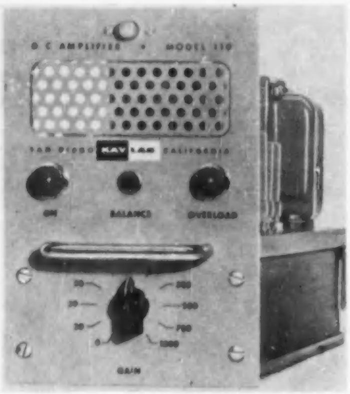


SPEED INDICATOR sensitive to small rpm variations.

Use of the Weston Frequency Responsive system allows the machine shown above to detect motor speed changes in automatically regulated systems. A tachometer indicator is provided to give visual indication of the full speed range. Speed changes as

small as ¼ of 1 per cent will be indicated for speeds as high as 80,000 rpm. Lack of vacuum tubes means maintenance-free operation, says the maker. *Weston Electrical Instrument Corp., 614 Frelinghuysen Ave., Newark 5, N. J.*

Circle No. 22 on reply card



DC AMPLIFIER uses chopper for stabilization.

The chopper stabilized dc amplifier shown here provides less than 2 mv drift through 40 hrs. The maker says this is accomplished through a chopper stabilization circuit—and with noise less than 5 microvolts, peak to peak at input, 3 cycle band, less than 5 microvolts rms for 750 cycle band, and less than 12 microvolts rms for 50 kc band. Gain remains constant to within 3 db from dc to 30 kc. Output is 25 with a 1,000 ohm load, with linearity better than 0.1 per cent. More information on the Model 110 dc amplifier is available from *Kay Lab, Box 16, San Diego 12, Calif.*

Circle No. 23 on reply card

LOW PRICED and small sized, recorder is portable.

The portable recorder shown above has advantages of low price and fast

pen speed—$\frac{1}{2}$ sec for full travel across the 5 in. wide chart. It is divided into two cases, weighing 25 lb all told, and operates on control signals in the millivolt range. *Machine Products & Engineering Co., Div. of Welltab, Inc., 1713 Yale Blvd., S.E., Albuquerque, N. Mex.*

Circle No. 24 on reply card

RADIATION MONITOR: A new area monitor, intended for use around reactors, records gamma and beta radiation separately on a strip chart recorder. A variety of rate ranges are available in the drift-stabilized machine. *Trott Electronics Co., 27 Gorham St., Rochester 5, N. Y.*

Circle No. 25 on reply card

CONTROL VALVES

SOLENOID VALVE has three packless parts.

Shown outside the device above (a three-way solenoid-operated valve) is its three moving parts. Its rate is 400 cycles per min. It easily adjusts to normally open or normally closed operation and is said to handle liquids or gases without leakage. Pipe sizes of $\frac{3}{8}$ or $\frac{1}{2}$ in. are accommodated. Either ac or dc coils are available. The unit can be completely cleaned and its parts replaced without removing the whole valve from its pipe line. *Automatic Switch Co., 391 Lakeside Ave., Orange, N. J.*

Circle No. 26 on reply card

RCA "Special Reds" provide that extra "life-line" you need in industrial electronic equipment, air, marine, and land-mobile communications, and unattended relay and transmission circuits—that extra margin of safety and dependability that *keeps things going!*

RCA "Special Reds" feature remarkable *stability,* excellent resistance to shock and vibration, exceptional *uniformity* of characteristics from tube to tube—and are backed by RCA for 10,000 hours minimum life!

RCA "Special Reds" are recommended for initial designs in industrial electronic equipment. They are excellent as replacements in existing circuits where there is a prototype operating under conditions within the ratings of the "Special Reds."

CONTACT YOUR LOCAL RCA TUBE DISTRIBUTOR TODAY. Ask for your free copy of the booklet "RCA Receiving Type Tubes for Industry and Communications" (form RIT-104).

RCA-5690—Full-Wave Vacuum Rectifier with separate heaters and cathodes.

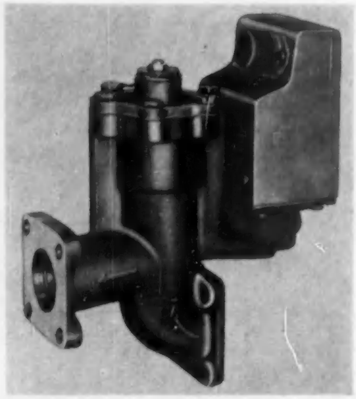
RCA-5691—High-Mu Twin Triode. Similar to the RCA-6SL7-GT, but has twice the heater current.

RCA-5692—Medium-Mu Twin Triode. Similar to the RCA-6SN7-GTB.

RCA-5693—Sharp-Cutoff Pentode. Similar to the RCA-6SJ7.

ELECTRON TUBES
RADIO CORPORATION OF AMERICA

NEW PRODUCTS



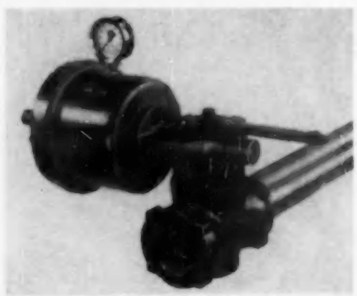
SOLENOID-TRIPPED valve is a pressure regulator.

Wide variations in air pressure or temperature have little effect on the performance of this pressure regulating valve. It holds downstream air pressure constant by means of a pilot-operated main valve. A solenoid bleed valve overrides the operation of the piston pilot to close the main valve, which is of the globe type. It takes unusually high temperatures: 1,000 deg F inlet plus 500 deg ambient *Hydro-Aire, Inc., 3000 Winona Ave., Burbank, Calif.*

Circle No. 27 on reply card

SOLENOID VALVE LINE: Conforming to JIC standards is a line of solenoid valves that are inoperable when their covers are removed and that can be manually operated otherwise. Pipe sizes accommodated are ¼, ⅜, and ½ in. *Automatic Valve Co., 37415 Grand River, Farmington, Mich.*

Circle No. 28 on reply card



VALVE ACTUATOR "fails safe" because of double chamber.

The valve actuator above features "fail safe" operation. If the operating air or gas pressure fails, the device will return the valve it controls to a set position. This action is accomplished

through the use of two chambers separated by a diaphragm. The diaphragm provides the means for moving the actuation rod. The second chamber accumulates pressure from the first to force the diaphragm to its starting position, should the pressure fail. Required pressure is from 15 to 100 lb. *Bettis Corp., 320 S. 66th St., Houston, Tex.*

Circle No. 29 on reply card

CHECK VALVE: A new pilot-operated check valve for use with 3/8-in. piping in industrial oil-hydraulic systems utilizes spring-closed poppet type construction. These valves can be used to flow in a given direction until opened by a remotely controlled pilot pressure. The rated capacity of the new 4 CG-03 line is 8 gpm. They are for systems with line pressures of up to 2000 psi. The pilot pressure required is greater than 40 per cent of the system pressure. *Vickers Inc., Detroit 32, Mich.*

Circle No. 30 on reply card

PULSE PRODUCTS

DIRECT READING counter dial indicates up to 100 turns.

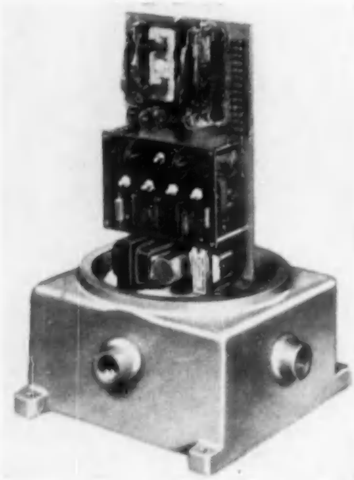
Plain to see, the dial above provides direct-reading ease in identifying the position of multi-turn potentiometer shafts. It affords readings to 9999 with up to 100 turns and is 1¾ in. deep by 2¼ diam. *Amerac, Inc., 116 Topsfield Rd., Wenham, Mass.*

Circle No. 31 on reply card

PNEUMATIC OSCILLATOR: A new pneumatic square wave generator is said to contain no moving parts. It is adjustable through a frequency range of from 3 to 50 cycles per min. Output amplitude can be from 0 to 30 psi, and top frequencies of 300

cycles per min can be proved for special applications. *Servo-Gauge Mfg. Co., 1450 Timber Drive West, Elmhurst, Ill.*

Circle No. 32 on reply card



REMOTE temperature reading system uses pulse coding.

A remote temperature reading system called the ST-8900 can operate wherever conventional communication facilities exist. Here's how the remote transmitting station, shown above, operates after receiving a start or command readout pulse from the receiving station: First, a series of pulses begin the temperature reading process. Next, the station transmits a pulse sequence to identify itself. Then, a series of pulses gives a direct indication of the temperature to the nearest degree. The normal span of reading is 130 deg F, but the top temperature measurement may be as high as 500 deg F. Broader spans can be achieved by a proportional lower accuracy. *Shand & Jurs Co., Berkeley 10, Calif.*

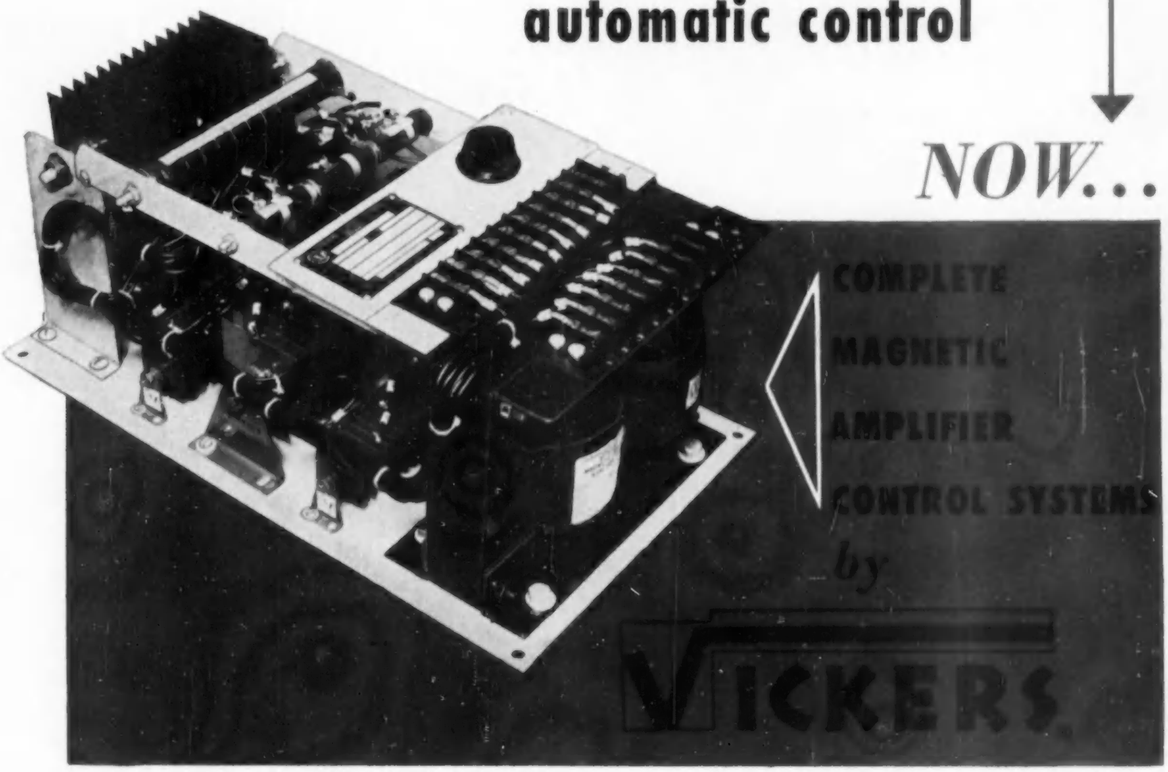
Circle No. 33 on reply card

NEW SCALER: You can preset a new six decade counter at any of nine intervals ranging from 100 to 1 million counts. It can be set to stop on reaching the preset elapsed time of from 100 to 100,000 sec. Counting rates go up to 60,000 cps. Input resolution is 5 microsec, and input circuit includes a 5 to 50 v pulse height discriminator. *American Tradair Corp., 34-01 30th St., Long Island City 6, N. Y.*

Circle No. 34 on reply card

for accurate, reliable automatic control

NOW...



FIRST to Produce Commercially-Available Magnetic Amplifiers

Vickers complete Magnetic Amplifier Systems are developed to meet the need for reliable and accurate control in today's rapidly-expanding field of automatic control in industry.

In addition to custom design systems for particular complex applications, Vickers offers a complete line of standard magnetic amplifiers from milliwatts to 50 kilowatts.

For your automatic control needs, Vickers' full resources, including special engineering skills and years of practical experience, are available to assist you in the solution to your problems.

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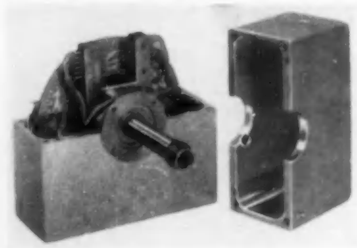


AN-DIG converter line has all types of coded discs.

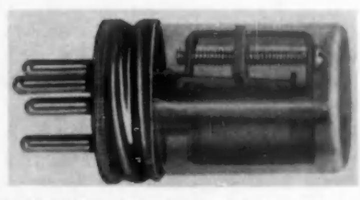
A line of the analog to digital converters similar to the one above is available with either non-ambiguous or incremental coding and in both binary and decimal form. The incremental coded type is available with torque as low as 0.01 oz-in. and a moment of inertia as low as 10 gm cm². *Wang Laboratories, Inc., 37 Hurley St., Cambridge, Mass.*

Circle No. 35 on reply card

PULSE AMPLIFIER: A new linear pulse amplifier includes a regulated power supply, an amplitude descriminator and three high speed binary counters. Its resolving time is one microsec, maximum input rate 100,000 counts per sec. *North American Philips Co., Inc., 750 S. Fulton Ave., Mt. Vernon, N. Y.*

Circle No. 36 on reply card

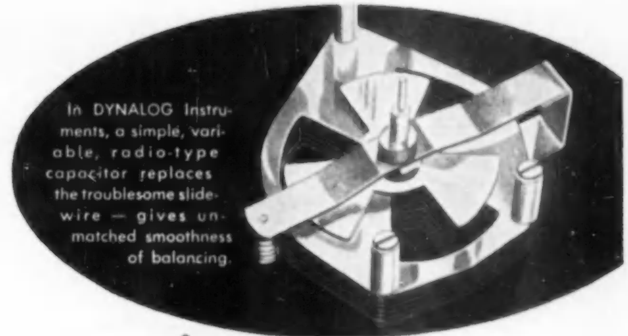
RELAYS & SWITCHES



FREQUENCY OPERATED relays make multiplexing easy.

A new series of low-cost TR frequency-operated relays operate in frequencies ranging from 40 to 170 cps with a 400 ohm coil as standard. A maximum of ten relays can be separately operated by appropriate control tones on a single circuit. *Potter & Brumfield, Princeton, Ind.*

Circle No. 37 on reply card



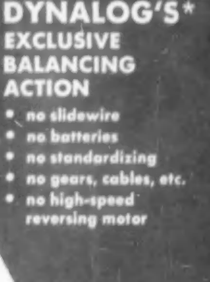
This potentiometer has no slidewire

STEPLESS CAPACITY-BALANCING

ELIMINATES SLIDEWIRE MAINTENANCE

DYNALOG'S* EXCLUSIVE BALANCING ACTION

- no slidewire
- no batteries
- no standardizing
- no gears, cables, etc.
- no high-speed reversing motor



There's no need to put up with worn slidewires and sticking electrical contacts . . . no need to periodically clean and lubricate balancing motors. DYNALOG design eliminates all this! Its simple variable capacitor and positive magnetic drive provide *continuous, stepless* balancing . . . *never* require attention!

DYNALOG's friction-free action provides high speed of response without wear. (There are only five moving parts, including the recording pen!) Sensitivity, unlimited by turns of slidewire winding, is 1/100 of 1%. And accuracy is a sustained 1/4 of 1%.

DYNALOG Instruments are available for use with resistance, voltage, capacity, or inductive type primary elements to measure and/or control any process variable . . . with unmatched smoothness. Write for Bulletin 427. The Foxboro Company, 361 Norfolk Ave., Foxboro, Mass., U.S.A.

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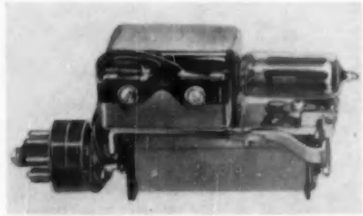
DYNALOG

ELECTRONIC INSTRUMENTS

NEW PRODUCTS

HEAVY LOAD MINIATURE RELAY: Contacts rated up to 20 amps are featured in a walnut-sized relay recently offered. Minimum coil operating power is ½ watt. Contact arrangement is single pole single throw. *Magnecraft Electric Co., 3352 W. Grand Ave., Chicago 51, Ill.*

Circle No. 38 on reply card



SENSITIVE RELAY carries its own built-on amplifier.

Currents as small as 15 millionths of an ampere will operate the relay shown above. The secret is the small amplifier on the back of the device. The result is current amplifications on the order of 10 million to one. Input power is less than 0.00011 watts, while the output can handle up to 1,150 watts. Ordinary 115 vac power operates the cold-cathode tube circuit, which draws no power in the absence of a control signal. Operating speed is about 50 millisec. The circuit is potted. *Industrial Electronics Co., Inc., Hanover, Mass.*

Circle No. 39 on reply card

IMPULSE COUNT SWITCH: When it's used as part of a machine tool control, a new preset counter can shut down an operation or station after the number of cycles that experience shows is the limit of a given tool's life. Easily set by a single pointer-type knob, the compact electro-mechanical device steps the knob toward zero with each completed machine cycle. *Hagan Mfg. Co., Moline, Ill.*

Circle No. 40 on reply card

ELECTRONIC SWITCH: The simultaneous presentation of two inputs on one scope is provided in dc to 15 mc operation by a new electronic switch. Both absolute and relative amplitude measurements can be made to within 2 per cent. The amplifier rise time is 0.023 microsec, input 1 megohm, and output impedance 93 ohms. *Telectronics Laboratory, Inc., 54 Kinkel St., Westbury, N. Y.*

Circle No. 41 on reply card

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(100) VARIABLE INDUCTORS. Vari-L Co., Inc., Catalog 9/55, 12 pp., and Bulletin 9/55-S, 12 pp. Describe a saturable-core reactor which is really a variable inductor for tuned circuits. Control current vs. frequency curves plotted.

(101) PLATE PIPE COIL. Thermo-Panel Div. of Dean Products, Inc. Bulletin 256, 4 pp. Dean calls this an improvement on pipe coils. The standard panel consists of two embossed 14-gage rolled steel plates welded together to form flow channels.

(102) VIBRATION MOUNTINGS. Vibration Mountings, Inc. Catalog G-55, 8 pp. Installations range from the heaviest impact machinery to instruments that do not create vibration but are affected by it. Chart helps determine minimum deflection required for a selected isolation efficiency.

(103) DOPPLER DATA TRANSLATOR. Potter Instrument Co., Inc. Data sheet. Describes an instrument that codes and records cyclic tape data on binary magnetic tape for a computer. Rate is 500 samples per sec; recording is continuous.

(104) DEPOSITED CARBON RESISTORS. Electroseal Products, Inc. Technical Information Bulletin 100, one sheet. Shows high-frequency response and temperature coefficient curves for axial and radial lead resistors. Tolerance 2, 5, or 10 per cent, noise factor minimal, wattage ratings conservative.

(105) POTENTIOMETER. The Bristol Co. Bulletin PI270. Describes the new high-speed recording Dynamaster pot. Recorder has full-scale pen travel across its 11-in. calibrated chart of only 0.4 sec.

(106) AN CONNECTOR CHART. The Deutsch Co. Wall chart, 22 x 28 in. Groups connectors by inserts, shells, and contact size, voltage rating, creepage, and spacing, and tells how to specify a complete connector assembly.

(107) PNEUMATIC REGULATORS. Conoflow Corp. Bulletin H-2, 8 pp. The pneumatic equipment described here includes filter-regulator combinations, relays, purge assemblies, and control panels. Cross-section and dimension drawings.

(108) PROCESS REFRACTOMETER. Consolidated Engineering Corp. Bulletin 1839, 8 pp. This Phillips Petroleum development records and controls by measuring the difference in refractive index between a standard and a sample.

(109) HYDRAULIC OIL PUMP. Lear-Romec Div. of Lear, Inc. Product Data Sheet 5-45, one page. Tells about a light (2.6 lb) and rugged aircraft pump for ambient temperatures of minus 65 to plus 165 deg. F. Rated capacity is 2 gpm at 3,750 rpm and 1,500 psi. Input is 2 hp.

(110) AIRBORNE CONNECTOR. Electronic Sales Div. of DeJUR-Amsco Corp. Bulletin CCC20, one sheet. Shows actual size of this miniature, lightweight, versatile unit. All dimensions clearly tabulated.

(111) PRESSURE DIFFERENCE TRANSMITTER. Hagan Corp. Bulletin MSP-130, 4 pp. Hagan says this instrument fills the need for transmitters that can measure in ranges exceeding several hundred pounds per square inch. It's usable at static pressures up to 3,000 psi.

(112) CLUTCHES & BRAKES. Dial Products Co. Catalog 955, 8 pp. These electromagnetic devices have OD's ranging from 0.920 to 1.500 in. and torque values up to 200 in.-oz.

(113) CONTROL VALVE OPERATOR. Industrial Controls Div. of Manning, Maxwell & Moore, Inc. No compressed air is needed here, because this item generates its own hydraulic power. Dc signal ranges from 0.5 to 5.0 ma.

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(114) VERSATILE SCOPE EXPANDER. Laboratory for Electronics. Bulletin, 1 page. Suggests a dozen applications for this instrument that are above and beyond its prime duty: expansion of the range of an oscilloscope.
(115) NEW DECKER LITERATURE. Decker Aviation Corp. Six data sheets. Cover Decker's rotor micrometer, capacitance-to-analog transducer, dynamic balancer, ionization transducer, comparator micrometer, and pressure meter.
(116) ELECTRONIC TESTING. Shasta Div. of Beckman Instruments, Inc. Catalog, 8 pp. This instrumentation line includes expanded scale voltmeters and frequency meters, vacuum tube voltmeters, oscillators, resistance bridges, power supplies, wide band amplifiers, a WWV receiver, and a decade inductor.
(117) TEMPERATURE CONTROLS. Burling Instrument Co. Catalog G-20, 4 pp. These differential expansion instruments operate on the bi-metallic principle, though they are not strip-operated thermostats. They handle temperatures ranging from sub-zero to 1,800 deg F.
(118) CONSULTING SERVICES. Cincinnati Research Co. Bulletin, 12 pp. Describes various ways in which industries can use consultants, and outlines fields of specialization of Cincinnati Research.
(119) ELECTRIC MOTORS. Howell Electric Motors Co. Bulletin N-100-R, 16 pp. Tells about the new Series 100 motors whose ventilation system provides 50 per cent more contact between cooling air and lamination.
(120) SYNCHRONOUS AND INDUCTION MOTOR. Holtzer-Cabot Divs. of National Pneumatic Co., Inc. Bulletin MO-3-5, 4 pp. About a new 3-in. diam motor that develops efficiencies of more than 30 per cent. The rotor in the synchronous model is unique.
(121) RAY PROJECTORS. The M. W. Kellogg Co. Booklet, 24 pp. Discusses sources of gamma radiation and three models of the "Kel-Ray" projector. Ray intensity and exposure guide included.
(122) PUSH-BUTTON ACTUATORS. Micro-Switch Div. of Minneapolis-Honeywell Regulator Co. Data Sheet P99. Describes the new Series 4MA and 5MA switch actuator. Indicates switch actuator series and actuator for specific needs.
(123) TEST EQUIPMENT. Weston Electrical Instrument Corp. Catalog R36A, 16 pp. The nine communication equipment testing instruments listed here include clamp voltmeters and ammeters, an industrial circuit tester, an electron tube analyzer, an oscilloscope, and a sweep generator.
(124) PHOTOELECTRIC PYROMETER. Electronics Corp. of America. Bulletin PT 556, 4 pp. This photoswitch model responds to temperature changes of 5 deg F without physical contact. Oxides, scale formation, smoke, or vapors do not affect accuracy.
(125) DEPOSITED CARBON RESISTORS. International Resistance Co. Bulletin B-4a, 4 pp. Presents comprehensive data on tests, applications, specs, tolerance, ranges and dimensions.
(126) THERMOCOUPLES. Revere Corp. of America. Engineering Bulletins 1601, 02, 03, and 04, 14 pp. Cover design and selection of thermocouples for liquid, gas, and surface temperature measurements.
(127) ELECTRON TUBES. Industro, Inc. Bulletin A1-55-IOM, 22 pp. Just about 1,000 tubes, arranged according to type, description, code, and list price, are catalogued here.
(128) METERS. Meter & Valve Div. of Rockwell Mfg. Co. Bulletin OG 409, 8 pp. Describes a new line of all-bronze Rotocycle meters (bulk and tank truck models) for industrial use. Flow rates range from 20 to 500 gpm.
(129) HOSE COUPLINGS. Titeflex, Inc. Form 7-55-20, 20 pp. Describes these couplings' simple construction and their unique swiveling action. They seal the line at the instant of disconnect.
(130) TIME DELAY RELAYS. A'G'A Div. of Elastic Stop Nut Corp. Bulletin SD-1, 4 pp. Feature here is a two-page selection chart that matches each Agastat relay with its respective characteristics and the job it is designed to do. Fifty-eight models treated.
(131) FLEXIBLE SHAFT ASSEMBLIES. Kupfrian Mfg. Corp. Catalog 5694, 12 pp. Presents full size illustrations of representative shaft assembly combinations. Tables list properties, dimensions, and tolerances.
(132) CLEAN, DRY AIR. Hankison Corp. Bulletin M-7155, 4 pp. Discusses components and operation of "Condensifilters", which condense and dry compressed air at pressures up to 200 psi. A moisture-vapor content chart evaluates water vapor.
(133) RATE OF FLOW CONTROLLER. Builders-Providence Div. of B-I-F Industries, Inc. Bulletin 600-J9A, 4 pp. These power-actuated units can be positioned by pneumatic, hydraulic, or electric sources. Accuracy is to plus or minus 3 per cent.
(134) AIR GAGING. Pratt & Whitney Div. of Niles-Bement-Pond Co. Circular 586, 24 pp. Covers the Air-O-Limit comparator, a pneumatic back-pressure gage that relates air clearance to part size.
(135) REACTOR SIMULATOR. Leeds & Northrup Co. Folder ND46-70-700(2), 4 pp. Tells how this machine electronically synthesizes most reactor types at a fraction of the cost of building and operating an actual reactor. Photos of components, dc block diagrams included.

(136) DIGITAL READOUT. Coleman Engineering Co., Inc. Technical Bulletin CR-179, 8 pp. This "Digitizer Application Data" covers equipment used with Coleman's an-dig converter. Shows the Digitizer schematic and circuit diagrams of each readout system.

(137) SWITCHES AND AN ACTUATOR. James Cunningham Son & Co., Inc. Bulletins 55-101, 55-102, and 55-111. Discusses two new crossbar switches, one limited to 10 links and 10 lines, that connect circuits in any combination, and a dc electromagnetic solenoid actuator.

(138) CONTROL RELAYS. Clark Controller Co. Bulletin PL 7305-PM, 8 pp. About a new line (10 models) of sectional-pole, heavy-duty 10-amp units with from two to 12 poles. Can take eight poles without double-decking. Each pole (a set of NO or NC contacts is independent.

(139) ACTUATOR. Weighing Components, Inc. Catalog 22, one sheet. Precisely and speedily positions valves, gates, slides, and other mechanisms electrohydraulically. Reaction time to an electrical signal is less than 1/1,000 sec.

(140) SELECTOR SWITCH. Electro Tec Corp. Brochure, 4 pp. Distinctions include miniature size, ultra-low torque, and precision. Available with up to 10 positions in a size 10 synchro housing. Can take temperatures ranging from minus 55 to plus 100 deg. C.

(141) DELAY LINES. Helipot Corp. Technical Paper 491, 7 pp. This paper, "Criteria and Test Procedures for Electromagnetic Delay Lines", by Helipot's Norman W. Gaw, Jr., and David Silverman, is the second on these Helidel devices.

(142) FLOWMETERS. Instruments Div. of Scully-Jones & Co. Bulletin, one sheet. Two new models feature a direct flow design whose flexible vane, traveling under flow, indicates on a calibrated scale. Model L is read by a scale, Model LP by inspection of the flow.

(143) INFRARED DETECTORS. Barnes Engineering Co. Bulletin "Optitherm Infrared Detectors", one sheet. Covers characteristics, construction, circuitry, and uses of these high-speed thermistor-type sensing elements.

(144) VALVES AND CONTROLS. Associated Valve & Engineering Co. Catalog A-155. Seven sections illustrate more than 100 products for nuclear and chemical industries. Includes capacity charts, tables.

(145) OSCILLOGRAPHIC RECORDING. Sanborn Co. Bulletin 1, 16 pp. Features of these "150" recording systems are their basic assemblies (1-, 2-, 4-, 6- or 8-channels) and their interchangeable preamplifiers.

(146) SUBMINIATURE RELAYS. Elgin-Neomatic, Inc. Brochure, 4 pp. Elgin calls its "neomite" the world's smallest precision relay and the first built in a standard transistor case for transistorized circuitry.

(147) PRINTED WIRING BOARDS. Electronic Components Dept. of General Electric Co. Brochure EP-45, 6-pg. gatefold. Presents layout and design data, specs on base and conductor materials, application characteristics, and advantages.

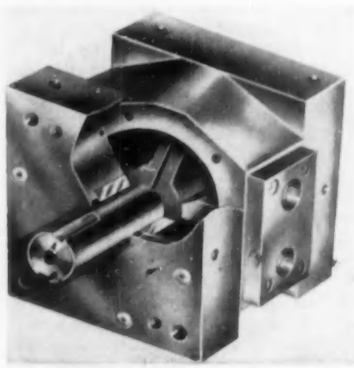
(148) SELENIUM RECTIFIERS. Rectifier Div. of Sarkes Tarzian, Inc. Selenium rectifier replacement guide (R2) and catalog 4c on the Centre-Kooled SR line.

NEW PRODUCTS

ROTARY ACTUATORS

ADJUSTABLE SPEED CONTROL: A range of motor speeds from 100:1 for motors from ½ to 4 hp is claimed for the VS-100. Single-phase power supplies the completely packaged and plastic-sealed electronic speed controller. *Reliance Electric & Engineering Co., 1088 Ivanhoe Rd., Cleveland 10, Ohio.*

Circle No. 42 on reply card



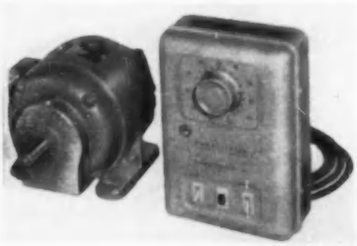
ROTARY ACTUATOR uses fluid or gaseous medium.

Many jobs requiring intermittent rotary motion, up to 280 deg, might make use of this oscillating torque motor. The Rotamotor operates on air, oil, water, or fire-resistant fluid mediums and is said to be leak-free. Since speed and force exerted depend upon the pressure of the power medium, outputs of either ounces or tons is possible. A fine piece of descriptive literature on the item is available from *Roto-Mation Motors, Inc., 525 S. Riverside, St., Clair, Mich.*

Circle No. 43 on reply card

ROTARY AIR MOTOR: A new model rotary air motor, weighing only 17 lbs delivers 2 hp at speeds up to 2,000 rpm on air line pressures from 30 to 90 psi. Four light vanes automatically take up wear and seal leaks in the new motor. *Gast Mfg. Corp., Box 117 N. Benton Harbor, Mich.*

Circle No. 44 on reply card



MAGNETIC SPEED controller provides 50:1 range.

Using simple magnetic circuitry, the motor speed controller seen above is applicable to motors up to $1\frac{1}{2}$ hp. Reversability, dynamic braking, smooth starting, and local or remote control are among the features of the mechanism. The Magne-Speed is available in two sizes from *Magnetic Amplifiers, Inc., 632 Tinton Ave., New York 55, N. Y.*

Circle No. 45 on reply card

ROTARY GEAR MOTORS: Applications requiring up to two hp of rotation may benefit from a new line of fluid motors. A 48:1 speed reducer is available as standard equipment. *John S. Barnes Corp., Rockford, Ill.*

Circle No. 46 on reply card

POWER SOURCES

COMPACT SOURCE gives out standard voltage.

This device, known at the "k-Volt Standard", provides a constant dc output through ambient temperatures as low as minus 55 deg C and up to 100 deg C. The $1\frac{1}{2}$ in. high, $1\frac{1}{4}$ in. diam unit is available with 26.5 vdc or 117 vac or dc to yield an output of 6 v or 1 v at 1 ma or 10 ma. Consumption is less than 1.8 watts. Life expectancy is better than 10,000 hrs and random drift less than 0.1 per cent through 1,000 hrs of operation. *Avien, 58-15 Northern Blvd., Woodside 77, N. Y.*

Circle No. 47 on reply card

NEW PRODUCTS

TRANSISTOR CIRCUIT POWER SUPPLY: Model C-22-2 provides a voltage range of 0 to 30 with a current range of 0 to 2 amps, electronically controlled. Regulation is within 0.1 v, and ripple to within 2 millivolts. Output time constant is approximately 0.1 millisec. The internal impedance is held to within 0.05 ohms. *Universal Electronics Co., 1720 Twenty-Second St., Santa Monica, Calif.*

Circle No. 48 on reply card

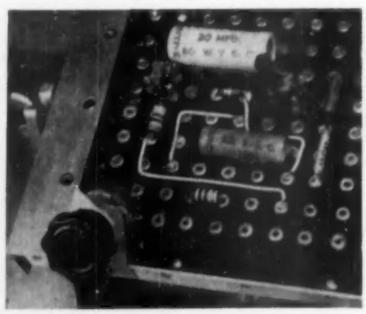
TRANSISTOR POWER SUPPLY: A new tubeless power supply, intended for transistor circuit development, offers from 0 to 50 at up to 10 ma on three independent output channels. Ripple is under 1 millivolt and regulation is to within ½ per cent at 50 v. Higher current models are available. *NJE Corp., 345 Carnegie Ave., Kenilworth, N. J.*

Circle No. 49 on reply card

TRANSISTOR POWER SUPPLY: From 0 to 100 vdc at 100 ma are offered in a new power supply offering calibrated output. Output can be controlled remotely by inserting a resistor across a two-terminal line. Regulation is to within 0.1 per cent, ripple to within ½ millivolt, and stability to within 0.15 per cent. *Electronic Measurements Co., Lewis St., Eatontown, N. J.*

Circle No. 50 on reply card

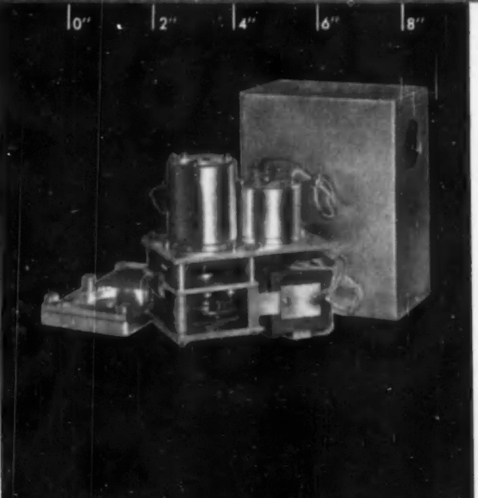
ASSORTED HARDWARE



BASIC BOARD simplifies printed circuit mockups.

The grommet-filled board above uses conventional wiring techniques to fa-

built to do just one servo control job . . . perfectly



An incremental synchro positioner before wiring to header and hermetic sealing. The synchro rotor is stepped in one or fifteen degree increments clockwise or counterclockwise depending upon which of four coils is momentarily energized by a d-c pulse. The synchro can be rotated any number of degrees or revolutions. The cylindrical member resets the synchro to electrical zero if a pulse is applied to the "reset" circuit.

Like all Transicoil servo assemblies, this incremental positioner "does the job right" because it was designed for a single application . . . by a company whose major function is to provide complete servo assemblies precisely engineered and manufactured to solve individual servo control problems.

Of course, if you merely want servo *components*, you'll find Transicoil's control motors, motor-gear train combinations, motor-gear train-generator combinations, and servo amplifiers built to the highest order of precision and accuracy. But it is in the "package" engineering of unique assemblies that Transicoil's experience and creative imagination offer the greatest value. And in most cases, these assemblies cost no more than the individual components would purchased separately.

That's why it pays to check your servo problems out with Transicoil first. Write outlining your problem, and ask for Transicoil's new gear-motor bulletin. You'll find it a mighty handy availability guide in designing for tight production schedules.

Transicoil
CORPORATION
Worcester • Montgomery County • Pennsylvania

cilitate breadboarding printed circuits. In addition, it provides a simple base to work on. *The Electromatic Co., P. O. Box 827, Wheaton, Maryland.*

Circle No. 51 on reply card

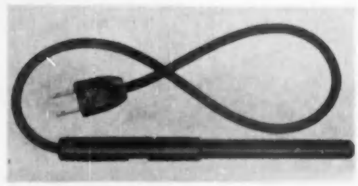
HOW ABOUT MAKING your own printed circuits?

Here is all you need to make your own printed circuits. In the kit is a 8½-by-5 in. piece of copper-clad laminate and everything needed to etch it. *Control Circuits, Inc., 24 Broad St., Middletown, Conn.*

Circle No. 52 on reply card

SUB-MINIATURE RESISTORS: A new line of resistors for transistorized or subminiature circuitry, only ¼ in. long and 3/32 diam, offers resistances from 0.1 to 0.5 megohm. Standard tolerances are within 1 to 1/10 per cent. Temperature coefficient is 20 ppm per deg C. The little resistors are wire-wound and available with either inductive or non-inductive windings. *Precision Resistor Co., Inc., 107 U. S. Highway #22, Hillside 5, N. J.*

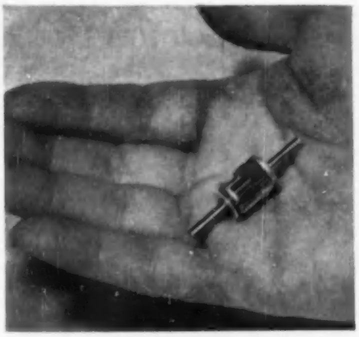
Circle No. 53 on reply card



PEN-LIKE DEVICE erases spots on magnetic tape.

This little machine, about the size of a king-sized fountain pen, erases small sections of magnetic recordings. The "Magnetic Erasing Pencil" should be useful to anyone who deals with information on small areas of magnetic tape. *Cinema Engineering Co., Div. of Aerovox Corp., Burbank, Calif.*

Circle No. 54 on reply card



TINY DIFFERENTIAL uses ball bearings, weighs 1/3 oz.

Believed to be the smallest in existence is the differential shown above, only [illegible] in. O.D. Its input shafts are $\frac{1}{8}$ in. diam. Static friction is overcome by 0.01 oz-in. *Pitometer Log Corp., 237 Lafayette St., New York 12, N. Y.*

Circle No. 55 on reply card

UNIVERSAL JOINTS: A line of new miniature universal joints accepts shafts as small as $\frac{3}{32}$ in. diam and has maximum outside diameters of as little as $\frac{1}{8}$ in. *Falcon Machine & Tool Co., 209 Concord Turnpike, Cambridge 40, Mass.*

Circle No. 56 on reply card

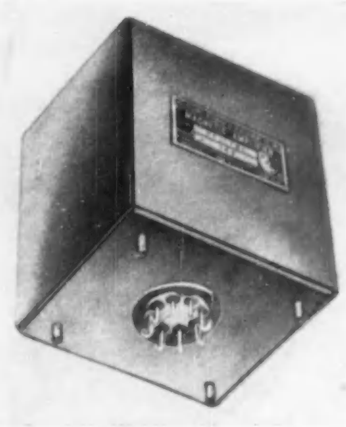
TINY POT gangs fourteen deep and weighs ½ oz.

Here are the pertinent characteristics of the pot seen above. *San Fernando Electric Mfg. Co., San Fernando, Calif.*

Resistances...from 5 to 25,000 ohms
Starting torque..........0.75 oz-in.
Rating..................0.3 watts
Shaft diam......................$\frac{1}{8}$ in.
Linearity........within 10 per cent
Rotation.........352 deg, electrical
360 deg, mechanical
Size..........$\frac{1}{2}$ in. diam, $\frac{3}{4}$ in. long

Circle No. 57 on reply card

NEW PRODUCTS



SERVO AMPLIFIER uses silicon transistors and magnetics.

The magnetic amplifier seen above will operate the parallel connected control windings of the 400 cps BuOrd MK7 or MK14 servo motor at full power. Designated the R40G7W6, the combination silicon transistor and magnetic amplifier device creates a voltage gain of over 2,000 when driving the MK7. Its bandwidth is from 0 to 70 cps. Operation at temperatures up to 85 deg C is possible through the use of silicon transistors. Increased stabilization is possible through the use of the dc component present in the output. *Polytechnic Research & Development Co., Inc., 202 Tillary St., Brooklyn 1, N. Y.*

Circle No. 58 on reply card

OPERATIONAL AMPLIFIER: For analog computer makers, Philbrick offers a new model plug-in operational amplifier with higher performance characteristics. The Model K2-X is physically interchangeable with earlier models. Some of its performance figures: gain, 30,000 dc; voltage range, minus 100 to plus 100 vdc; power requirements, plus 300 and minus 300 vdc. *George A. Philbrick Researches, Inc., 230 Congress St., Boston 10, Mass.*

Circle No. 59 on reply card

MINIATURE RESISTORS: Available with tolerances within 0.05 per cent is a new line of miniature resistors that display temperature insensitivity to the extent of 20 ppm per deg C. Ratings are under one watt, and sizes under ¼ in. diam. *The Daven Co., 530 W. Mt. Pleasant Ave., Livingston, N. J.*

Circle No. 60 on reply card

ABSTRACTS

Hydraulic Analogs

From "Hydraulic Analogue Method for Calculation of Thermal Gradients", by Eldon L. Knuth and Emerson L. Kumm, Aerophysics Development Corp. American Rocket Society paper No. 214-55.

The effects of atmospheric heating of the surfaces of high-speed missiles have emphasized the need for studies of the effect of transient temperature distribution through various materials under different conditions. Arbitrary changes in the environment (variation in heat-transfer coefficient and surrounding environment temperature) during an experiment make an analytical solution impractical. Resort to equations using finite differences often results in lengthy iterated calculation procedures or graphical techniques. If, in addition, temperature changes are such that noticeable variation in the material's thermal properties occur with the anticipated change in temperature, then an analog approach to the problem may be necessary.

Many of the difficulties encountered in using hydraulic analog computers in the past have been largely removed through recent availability of the uniform small bore precision tube. Although a number of researchers developed hydraulic analogs of heat flow problems, none has described a simple way to simulate variations in a material's thermal properties with change in temperature. An air flow analog described by M. B. Coyle in the proceedings of the Institute of Mechanical Engineers (England), 1951, took account of changes in a material's thermal properties by step changes in the cross sectional area of air capacitors. The method described in this paper for making changes in capacitor cross-sectional area is simplified from that used by Coyle. Three-dimensional cams are cut according to the desired change in capacitance-versus-pressure and inserted into water tower capacitors.

Also, the analog is extended to allow variations during an experiment in the surface heat transfer coefficient and environment temperature. Extensions are also made to allow the simulation of surface fusion and arbitrary surface heat transfer.

Its Application

One of the complicating factors in

the study of heat transfer in materials under conditions of forced-convected heat transfer in the presence of very high temperatures is the fact that the temperature through the thickness of the material may vary appreciably. For instance, a 0.5 in. thick wall of low-carbon steel at 1,000 deg F subjected to an environment of 4,000 deg F with forced-convected heat-transfer coefficient of 0.1 Btu/sq ft/sec/deg F might begin to melt its outer surface before the inner surface had appreciably changed temperature. If the melted surface is removed by air forces, then a time-wise step calculation is possible, equating the surface heat flux to the enthalpy change of the melted material. The scope of the application of the hydraulic analog to transient heat transfer is principally to those cases where a relatively large temperature gradient exists in the material undergoing the test conditions with or without surface fusion.

The paper shows the similarity between the equations describing heat flow and fluid flow in the analog. Boundary conditions which occur principally in aerodynamic heating are also considered.

How It's Built

Basically, the simulator consists of ten sections of capillary tubing connecting ten water towers (capacitors). The choice of tube diameter (0.101 in.) enables 1 second of heat-flow time to be analogous to 50 sec of fluid-flow time, and 1 in. of heat path to be analogous to 98 in. of liquid path. Different lengths of tubing were cut and connected by valves to allow a wide variety of combinations up to 89 in. of fluid flow.

The recovery-temperature simulator consisted of a liquid-supply system designed to supply liquid at a prescribed head to the boundary-layer simulator. A check of the computer with calculated data indicated that its overall results were accurate to within 5 per cent.

Surface Fusion

Melting of the wall surface can be approximated in increment fashion by allowing overflow to occur at the height equivalent to melting temperature and removing this overflow to simulate the absorption of the latent heat of fusion. Surface erosion is simulated by using bypass valves to short circuit the hydraulic capacitors and resistors as erosion progresses.

During the computer operation the length of capillary tubing in the boundary layer simulator and the setting of the fluid supply is varied according to a prescribed schedule. The height of the liquid in the ten hydraulic

capacitors is read visually and recorded at preselected intervals. When the run is completed, the head readings are converted into temperature values.

Piping Effects Valves

From "Effects of Adjacent Piping Configurations on Control-Valve Characteristic and Capacity", by G. F. Brockett, Fisher Governor Co., and W. J. L. Kennedy, Stone & Webster Engineering Corp., ASME Paper No. 55-A-138

The care used in specifying control valves in the engineering stages of a project, and the efforts of manufacturers to provide precise valve characteristics and capacities, are often partially nullified by poor installation practices. After sizing, the actual installation layout is then turned over to piping designers, who, in general, give little thought to the control functions of the valve, or to the effect which piping arrangement immediately adjacent to the valve will have on its performance.

The paper is essentially a collection of fifteen graphs showing the change in characteristics of plug valves of various sizes, using air and water, when operated at different pressures and pressure drops in association with reducers, plug cocks, elbows, etc.

Test Conditions

In the test results, the basic capacity of the control valve is plotted for reference. It is common practice to include the pressure drop across the entire control-valve manifold under the pressure differential available for control. That is, if 10 psi drop is allowed for control, 2 psi of this may be used in the piping immediately adjacent to the control valve. The authors have followed this practice in the test results; the control valve and its adjacent piping were considered a system and treated as a unit in assigning pressure drop and calculating flow.

It's obvious that a reduction in effective capacity of the control valve results, but this does not insure that these effects will be compensated for. If it were not true that many control valves are oversized by duplication of safety factors, this effect would be more commonly noticed.

Although the valve capacity decrease is predictable, the effect of adjacent piping on valve characteristics is not obvious and is shown to vary considerably.

NEW BOOKS

T. J. Higgins reviews a process control book . . .

An Introduction to Process Control System Design. By A. J. Young, Head of the Central Instrument Laboratory, Imperial Chemical Industries Limited. 379 pp. Published by Longmans, Green and Co. Ltd., London, England. 42 shillings. Available in U.S. from Longmans, Green, New York City.

In the reviewer's opinion, this is the best book on process control theory and design which has been written in English. It joins basic feedback control theory with empirical knowledge gained from operating experience to make a coherent whole. It is written by an engineer with a comprehensive grasp of modern control theory, and an extensive acquaintance with current unit design techniques. This book fills a long-standing need of America and British instrumentation and process control engineers—it is in English, is up-to-date, and uses only simple analysis.

In his preface the author states his belief "that a simpler, almost non-mathematical, treatment of the basic principles of process control using the frequency response approach will be welcomed by many who wish to amplify their practical experience and by . . . newcomers to the field . . .".

The first of 19 chapters, "Economics", outlines the economic grounds underlying choice of the type of control for the plant. Chapters 2, "The Closed Loop" and 3, "Plant Characteristics" explain the essential differences between open and closed-loop control and illustrate, with examples, the basic plant features which enter into analysis. Chapters 4, "Systems of Exponential Transfer Stages" and 5, "Plant Controllability" explain in detail the analytic treatment of a cascaded series of single-lag stages.

The frequency-response approach was chosen as the basic method of analysis because it permits basic understanding with simpler mathematics than other techniques. Accordingly, Chapters 6, "The Frequency Response of a Plant" and 7, "Experimental Frequency Response Analysis" advance the basic theory and experimental techniques evolved by the author and his colleagues for determining the frequency response characteristics of plant components.

To predetermine the control be-

havior of a plant, controller frequency response must be known also. Thus Chapter 8, "Characteristics of Theoretical Controllers", describes the frequency characteristics of idealized controllers of proportional, integral, derivative and compounded nature. Chapter 9, "The Operation of a Continuous Control System", discusses the combined characteristics of plant and controller in closed-loop operation.

Chapter 10, "Prediction of Controller Settings, Control Quality and Plant Controllability" is somewhat subsidiary. Its prime object is to demonstrate that the control quality for a given controller hinges, essentially, on the characteristics of the plant.

Subsequent chapters consider (11), "The Basic Principles of Pneumatic Controllers"; (12) "Some Three-Action Pneumatic Controllers"; (13), "Electric, Electric-Pneumatic, and Hydraulic Controllers".

Chapter 14, "Measuring and Transmission Lags", describes the character and influence of phase lags and attenuations of auxiliary components of the closed-loop system. In Chapter 15, "Transfer Stages", the frequency response characteristics of various types of transfer stages in the plant are considered as compounded of simple lag stages. Lumped and distributed-parameter stages, independent and interacting, are discussed at length and illustrated by examples.

Next, in Chapter 16, "Valve Characteristics", the commonly-used corrective control valve is discussed in general terms as an important element of a control system. It is shown by example that satisfactory control quality often hinges on a proper choice of this element.

The text is closed out by Chapters 17, "The Effect of Disturbance", a consideration of the effects on plant performance of an undesired disturbing signal acting at an arbitrary point in the system; 18, "Complex Control Systems", being an introduction to multiple-loop systems; and finally 19, "System Design", summarizing the principles discussed in preceding chapters and describing a somewhat personalized technique for designing a process control system based on these principles.

There are 6 appendices: the first on differences of terminology in various countries.

Thomas J. Higgins
Professor of Electrical Engineering
University of Wisconsin

Printed Circuits

Proceedings of the Symposium on Printed Circuits. 122 pp. Published by Engineering Publishers, GPO Box 1151, New York 1, N. Y. $5.00

This book contains, in complete form, the technical papers presented at the 1955 Symposium on Printed Circuits, which was sponsored by the Engineering Department of Radio-Electronics-Television Manufacturers Association with the participation of the Professional Group on Production Techniques of the IRE. The pertinent questions and answers that followed the presentation of each paper are included.

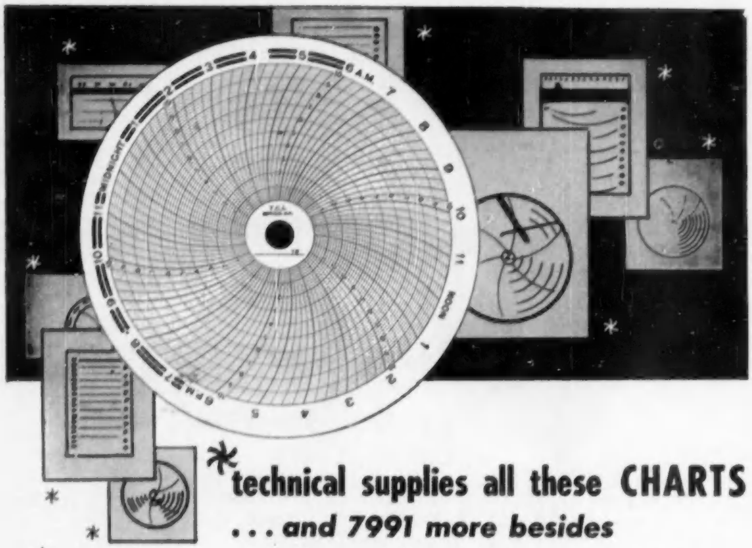
The papers cover both theory and practice—materials components, design and production, testing and evaluation, and reliability and management problems. All the methods of printed circuitry currently in commercial use are discussed. There are case studies of their use in reducing manufacturing costs.

Mechanisms by the Carload

Mechanism. *Joseph Stiles Beggs, Hughes Aircraft Co. 6½ by 9½ in., 418 pp. Published by McGraw-Hill Book Co., New York City.*

While some attempt is made in this book to carry out a continuing line of thought, it remains basically a detailed examination of a wide variety of mechanisms, each pretty much standing on its own. The basis of a course in advanced kinematics at UCLA, it begins with a discussion of the required mathematical tools needed to thoroughly analyze complex mechanical systems, but with the start of the third chapter introduces the reader to basic facts about a wide variety of specific devices. Gears of every description, and mechanisms associated with them, plus information on their manufacture, comprise the bulk of the third chapter. Next come cams, rotary drives, linkages, tension and flexural links, compression links (including fluids), computing mechanisms (mechanical calculators and electromechanical analog computer components), control mechanisms (this tends to be a rather weak section), a fact-packed chapter on Newtonian mechanics, and the usual compendium of interesting gimmicks.

Partially because of the unusual number of diagrams and photos (most of them excellent) this book is a truly interesting one to thumb through. It avoids the obvious and does a thorough job on the complex gadgets that demand dynamic analysis.



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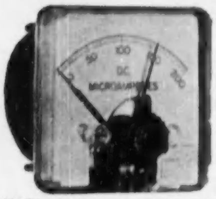

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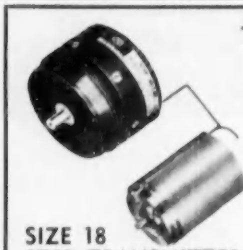

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WHAT'S AHEAD: MEETINGS

DECEMBER

American Chemical Society, 1955 Christmas Symposium on Process Instrumentation and Control, Princeton University, Princeton, N. J. Dec. 29-30

JANUARY

National Simulation Conference, Institute of Radio Engineers, Dallas-Fort Worth Chapter (Professional Group on Electronic Computers), Hotel Baker, Dallas, Texas. Jan. 19-21

American Institute of Electrical Engineers, Winter General Meeting, Statler Hotel, New York. Jan. 30-Feb. 3

FEBRUARY

Institute of Radio Engineers, Eighth Annual Southwestern Conference and Electronics Show, Municipal Auditorium, Oklahoma City, Okla. Feb. 9-11

Louisiana State University, 1956 Conference on High-Speed Computers, Baton Rouge, La. Feb. 15-17

MARCH

Institute of Radio Engineers, National Convention, Kingsbridge Armory and Waldorf-Astoria Hotel, New York. Mar. 19-22

American Society of Mechanical Engineers, Instruments and Regulators Div., Second Divisional Conference, Princeton University, Princeton, N. J. Mar. 26-27

APRIL

Special Technical Conference on Magnetic Amplifiers, sponsored by American Institute of Electrical Engineers, Institute of Radio Engineers, Instrument Society of America, Hotel Syracuse, Syracuse, N. Y. Apr. 5-6

American Institute of Electrical Engineers, Conference on Recording and Controlling Instruments, Bradford Hotel, Boston. Apr. 26-27

MAY

American Society for Testing Materials, Fourth Conference on Mass Spectrometry, Netherlands Plaza Hotel, Cincinnati, Ohio. May 27

The National Merit Scholarship Corporation

Business is Offered Big Dividends on Investment in Higher Education

Business firms searching for a satisfactory avenue to provide financial aid for our colleges and universities now have a new opportunity of major importance. It is provided by the National Merit Scholarship Corporation, which has offered to devote $8 million to matching, dollar for dollar, gifts by business firms for college scholarships and supplemental gifts to the institutions where the scholarships are used.

The McGraw-Hill Publishing Company is availing itself of the opportunity to establish ten National Merit Scholarships. They will be known as the McGraw-Hill Merit Scholarships. The scholarships are to be awarded to qualified candidates for a four-year college course in the fields of science, engineering and the other professions and the liberal arts. There will be no limitation, beyond the appropriate professional accrediting, on the college or university selected by a successful candidate. As part of a continuing program to aid higher education and educational institutions, McGraw-Hill is happy to be able to share in what it believes to be the constructive educational endeavor of the National Merit Scholarship Corporation.

The National Merit Scholarship Corporation, an independent agency financed initially by gifts of $20 million from the Ford Foundation and $500,000 from the Carnegie Corporation, has three major purposes which are closely related. They are:

1. To locate those of the nation's young men and young women who are best equipped to go to college.

2. When necessary, to help these young people go to college by giving them financial aid.

3. To help colleges and universities meet the full cost of the instruction of those to whom National Merit scholarships are granted.

At present about half of the nation's top high school graduates do not go to college. The principal reason is that they do not have the money required.

To Save Unused Brain Power

The National Merit Scholarship Corporation will strive to eliminate this dangerous neglect of top-flight ability. To this end it is inviting the nation's high schools, numbering more than 24,000, to participate in its program by designating as available candidates for National Merit scholarships the top 5 percent of their senior classes. Those so designated are then invited to take a series of tests and to submit reports designed to assure selection of the very best talent in each state. The number of scholarships to be allotted to each state will be proportionate to the number of high school graduates in the state.

The winners, the total number of whom will be determined by the amount of money the Scholarship Corporation has available, will be eligible for awards. For those who need no financial help to go to college there will be honorary awards of $100. For those who must have help the Corporation will grant scholarships covering as much as necessary

of the cost of instruction and living expenses for a four-year college course.

Colleges Get Financial Help

The provision of funds to cover the students' expenses does not, however, solve the financial problems faced by many colleges. That is because the tuition charges paid by the students do not cover the cost of the instruction. The deficit must be met by drawing upon endowment funds, gifts, grants, and other available sources.

Consequently, to prevent holders of National Merit scholarships from imposing any additional financial burden on the colleges and universities they elect to attend, the Corporation will make a supplementary grant to these institutions. The supplementary grant will be the equivalent of regular tuition charges made by the school, with a top limit of $1,500 a year for both the tuition and the supplement.

As the scholarship grants to the winning students will vary, depending upon how much financial help they need, so will the supplementary grants vary from one college to another, depending on their regular tuition charges. However, it is anticipated that on the average the full cost of a National Merit scholarship—including aid to the student and the supplement to the college—will be about $1,500 a year.

Many business firms will find a compelling appeal in a program which is designed at once to mobilize the nation's intellectual resources more effectively and, in the process, give very badly needed financial help to our colleges and universities.

Two For One Return Offered

However, there are numerous other inducements to business firms to finance National Merit scholarships. These scholarships may:

1. Carry the name of the firm or be named in honor of someone designated by the firm.

2. Be limited to use in types of colleges of particular interest to the sponsoring firm.

3. Be limited to a college course, such as science, engineering or liberal arts, of special concern to the sponsor.

4. Be restricted to candidates or institutions in geographic areas specified by the sponsor.

In addition to these advantages there is a special financial inducement to help the Merit Scholarship program. It is that for every Merit scholarship a firm or individual finances, the Corporation will, up to the limit of $8 million, match the funds and make another National Merit scholarship available.

There are many good ways of helping our financially beleaguered colleges and universities, and many corporations are already using one or more of them.* For those companies that can do so without embarrassing complications one of the best ways is to make unrestricted gifts directly to the institutions. But this new way provided by the creation of the National Merit Scholarship Corporation (Address: 1580 Sherman Avenue, Evanston, Illinois) has the broad appeal of serving two purposes of transcendent importance simultaneously. The purposes are to see that our best brains are fully trained and utilized and that our colleges and universities, crucial contributors to this process, are helped at the same time. Business will serve the nation and its own community well by giving the National Merit Scholarship Corporation generous help.

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* These, as well as the plight of our colleges and universities, are discussed in a pamphlet, "Business Aid to Our Colleges and Universities," which embodies a series of five editorials which appeared in all McGraw-Hill publications. Copies of the pamphlet can be obtained without charge by addressing the Department of Economics, McGraw-Hill Publishing Company, Inc., 330 West 42nd Street, New York 36, New York.

Methods of helping our colleges and universities financially are also outlined and discussed in a pamphlet, "Aids to Corporate Support of Higher Education," which may be obtained without cost by addressing the Council for Financial Aid to Education, 6 East 45th Street, New York 17, New York.

This message is one of a series prepared by the McGraw-Hill Department of Economics to help increase public knowledge and understanding of important nationwide developments that are of particular concern to the business and professional community served by our industrial and technical publications.

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EMPLOYMENT OPPORTUNITIES

NATIONAL COVERAGE

The Advertisements in this section include all employment opportunities — executive, management, technical, selling, office, skilled, manual, etc.

- Positions Vacant
- Positions Wanted
- Part Time Work
- Civil Service Opportunities
- Selling Opportunities Wanted
- Selling Opportunities Offered
- Employment Agencies
- Employment Services
- Labor Bureaus

DISPLAYED —RATES— UNDISPLAYED

The advertising rate is $17.80 per inch for all advertising appearing on other than a contract basis. Contract rates quoted on request.

An advertising inch is measured ⅞" vertically on a column — 3 columns — 30 inches to a page.

Subject to Agency Commission.

$1.80 per line, minimum 3 lines. To figure advance payment count 5 average words as a line.

Box Numbers—counts as 1 line.

Discount of 10% if full payment is made in advance for 4 consecutive insertions.

Not subject to Agency Commission.

Send NEW ADS to CONTROL ENGINEERING, 330 W. 42nd St., N. Y. 36, N. Y., for February issue closing December 29th

92,000 hours from now!

It is difficult to realize that this historic "flying machine" is just 92,000 working hours old.

From that 1910 beginning to today's new multi-jet Navy XP6M SeaMaster, Martin has developed and produced a new aircraft design every 1500 hours of the working calendar.

On this backlog of experience—unmatched by any other aircraft company in the world—one of the youngest and most dynamic managements in the industry is engineering new methods that are thousands of hours ahead of the aircraft calendar.

You would do well to find out what's happening at Martin—and what the opportunities there in AERODYNAMICS, ELECTRONICS, STRUCTURES, PROPULSION and NUCLEAR POWER might do to speed up your own calendar of progress.

Contact J. M. Hollyday, Dept. C-1, The Martin Company, Baltimore 3, Maryland.

MARTIN
BALTIMORE

ENGINEERS

PERMANENT CREATIVE OPPORTUNITIES FOR

ELECTRICAL AND MECHANICAL ENGINEERS

AT

Bendix

Immediate openings for . . . .

SENIOR COMPUTER ENGINEER

At least five years experience with analog computers with control applications. A degree in electrical engineering, or math and physics required. Activity is in the field of aircraft and missile power plant controls, including gas turbine, ram jet, and rocket types. Work will be with hydra-mechanical pneumatic and electrical components. The fuel metering research facility includes an analog computer and jet engine simulators.

MAGNETIC AMPLIFIER SYSTEMS ENGINEER

Electrical engineer supervisory capacity on research and development of magnetic amplifier circuitry, control systems, and component design and testing, supervising other engineers and technicians.

COMPUTER ENGINEER

Graduate engineers thoroughly qualified as a digital computer programmer, capable of handling engineering and production calculations, to train present personnel in preparation of data for computer applications. Set up new applications. Work with complex dynamics and control problems characteristic of the jet engine fuel system and landing gear fields.

LIQUID PROPELLANT ROCKET CONTROLS ENGINEER

Mechanical or electrical engineer to supervise the research and development of liquid propellant rocket controls, systems design, component design, development and testing.

The salary of these positions will be determined by your ability and experience.

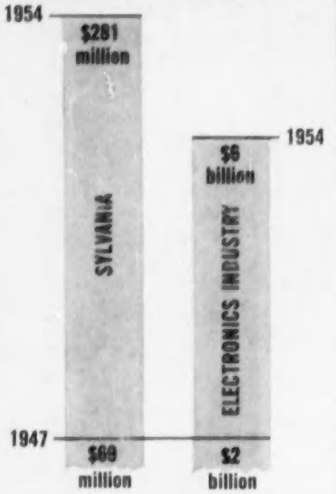
Send detailed resume listing education, engineering experience, and salary requirement to:

**TECHNICAL EMPLOYMENT DEPARTMENT
BENDIX PRODUCTS DIVISION OF
BENDIX AVIATION CORPORATION**
401 North Bendix Drive
South Bend 20, Indiana

We guarantee you an immediate reply—

ENGINEERS

SYLVANIA grows 33% faster than electronics industry



Your Future Lies with a GROWTH Firm in a GROWTH Industry

You can move up fastest and most securely with a firm that grows ... in an industry that grows.

Projected growth of the electronics industry is more than double for the next ten years. Past indications prove that your best chance for a career is with Sylvania ... in the past eight years Sylvania has grown 33% faster than the electronics industry of which it is a part.

Join Sylvania now and grow with it.

WALTHAM Engineering

Majors in E.E., M.E., Math, Physics. Research & Development experience in—

- Countermeasures
- Systems Analysis
- Transistor Applications
- Noise Studies
- Antenna Res. & Dev.
- Systems Development
- Mechanical Design
- Miniaturization
- Digital Computer Circuits & Systems
- Circuit Designs
- Shock & Vibration
- Technical Writing
- Missile Analysis

Missile Systems Laboratory

- Radar Research & Development
- Missile Guidance & Ground Equipment Analysis
- Systems Evaluation Operations Research

BUFFALO Engineering

Majors in E.E., Math or Physics. Experience in Advanced Development and Product Design

- Information Theory
- Advanced Circuit Design
- VHF-UHF Systems Design & Evaluation
- Logical Circuit Design
- Mathematical Analysis for Numerical Computation
- Pulse Techniques
- Data Processing Devices
- Components & their Applications
- Magnetic Amplifier Techniques
- Servo Techniques & Applications
- Digital Computer Design
- Control Circuits & Devices

INTERVIEW & RELOCATION EXPENSES WILL BE PAID BY SYLVANIA

Sylvania provides financial support for advanced education as well as liberal insurance, pension and medical programs.

Please forward resume to: Professional Placement Supervisor

Thomas A. Tierney	Randall A. Kenyon
100 First Ave.	175 Great Arrow Ave.
Waltham, Mass.	Buffalo 7, N.Y.

Your inquiries will be answered within 2 weeks

SYLVANIA

SYLVANIA ELECTRIC PRODUCTS INC.

ENGINEER

An Interesting Assignment In an Advanced

GUIDED MISSILES PROGRAM

You'll be responsible for keeping abreast of "the state of the art" in evaluating, selecting and recommending radiation - type fuzing equipment for system application in missile atomic weapon's fuzing and arming systems. This includes both missile-borne equipment and field test equipment employed for radiation-type fuzing.

This position with General Electric offers numerous personal and professional advantages, including excellent salary fine working and living conditions, technical courses, and other benefits.

Please send resume to:

MR. JAMES HEVELIN
Special Defense Projects Dept.
Room 206C

GENERAL ELECTRIC

2900 Campbell Avenue
Schenectady, N. Y.

ASSISTANT WORK MANAGER

To set up and supervise production lines and for general plant supervision. An experienced, capable engineer has a real future with this substantial, expanding firm of established reputation. Located in Southwestern city with unusual climatic advantages and recreational facilities. Resume will be held in strict confidence.

P8596, Control Engineering
520 N. Michigan Ave., Chicago 11, Ill.

ENGINEER

M. E. or E. E.

DIGITAL COMPUTER DEVELOPMENT

Excellent opportunity to join an expanding, stable company, with an outstanding position in the precision electronic control industry.

Opening now available for an engineer able to assume responsibility for the development of complete systems for fire control and guidance, or major portions of such systems. Work will include research and development in the field of complex analog or digital computers.

A degree in electrical or mechanical engineering is required or the equivalent in experience. Send resume in confidence to:

Technical Personnel Dept. 2-500

ARMA

Division American Bosch Arma Corp.
Roosevelt Field, Garden City
Long Island, N. Y.

Dear wife and kids:

Got here O.K. today. Couldn't wait to tell you what I think of Farnsworth and Fort Wayne. It's more than a place to work.. it's a way of life! Most of the folks here own their own homes. There are no row houses and that cottage in the country is real and only 10 minutes from everywhere.

Schools? There are 50 of them (full time.. no half day shifts!) 5 beautiful High Schools and I can take grad work at Purdue here at Farnsworth's expense!

This is also a town of churches... 132 in a town of 135,000 that boasts one of the lowest juvenile delinquency rates in the country.

There's also a full size, full season symphony orchestra ... World championship basketball and hockey in a new 3 million dollar coliseum that's out of this world. (Are you listening, Jackie?)

Tell Joe and his wife to start packing because there's plenty of room here for more engineers like him in R and D and systems engineering in missiles, radar, antennas, microwaves, test equipment, countermeasures, transistor applications and other phases. Tell him to write the Technical Employment Manager, Farnsworth Electronics Co. (a division of IT&T) at Fort Wayne, Ind. He'll be glad he did.

I can't wait until you and the kids get here... I know you'll love it. And, like they say at Farnsworth, "Very, very few ever leave it."

Love Jack

ELECTRONIC ENGINEERS

Guided Missiles Test

Join General Electric in a position created by expanding operations in the guided missiles field. Your assignment: developing pre-launch confidence testing, circuit design and component design of all sub-systems of a missile system.

To qualify you should have experience in the development and design of aircraft or missile system test equipment plus a B.S. in EE with Electronics Option. Salary is excellent and living conditions in this upper New York State location are attractive.

Please send resume to:

MR. JAMES HEVELIN
Special Defense Projects Dept.,
Rm. 206C

GENERAL ELECTRIC

2900 Campbell Avenue
Schenectady, New York

CHEMICAL ENGINEER

Leading manufacturer of industrial instruments located in residential community near Boston offers permanent position to qualified chemical engineer to assist chemical industry sales manager in application and sales development. Two to five years experience in chemical plant design or operation or instrumentation desirable. Include comprehensive outline of education and experience in your reply.

P-8181, Control Engineering
330 W. 42 St., New York 36, N. Y.

CHIEF ENGINEER

Exceptional position open for graduate mechanical engineer, age 35-45, as head of an engineering department for company in compressed gas industry.

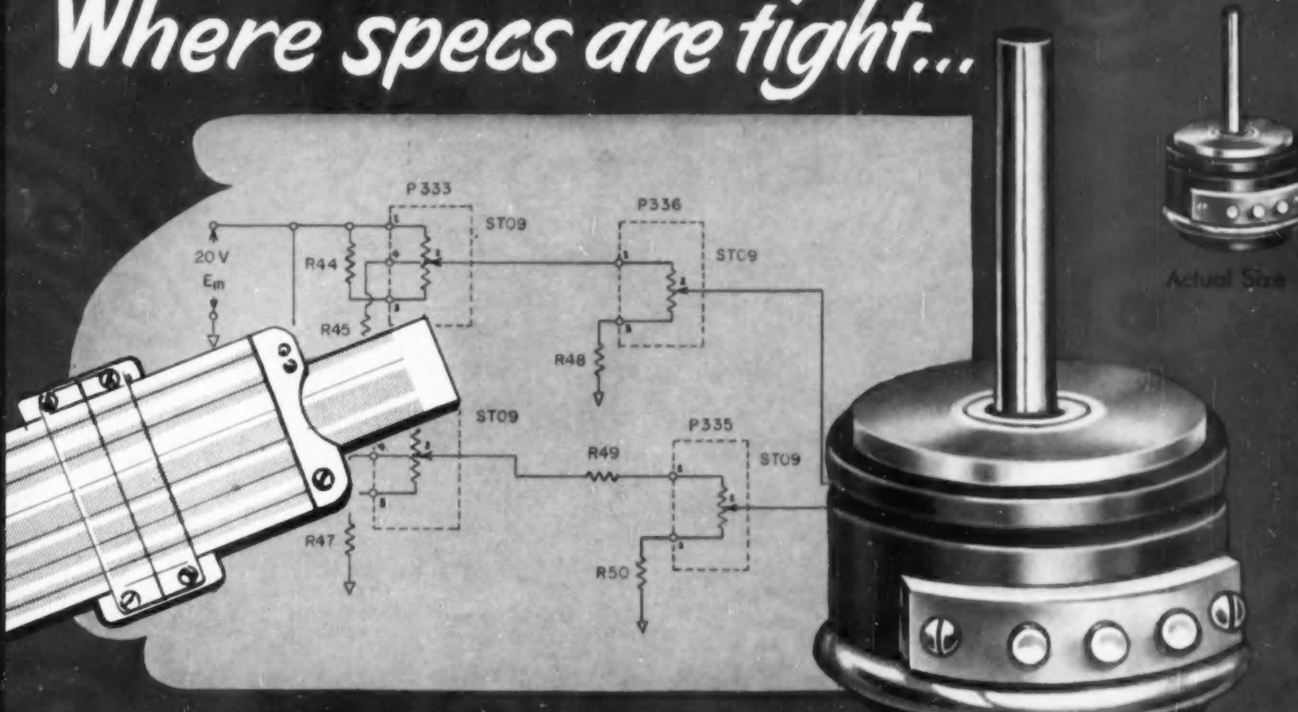
Five to ten years experience required in product design and product engineering involving manufacture of pressure regulating equipment and flow control apparatus. Previous experience in organizing and managing an engineering department is preferred. This is a top position with a long established firm in the midwest, manufacturing and distributing on a national basis, products used by hospitals.

Salary open. Will pay interview expenses. Please state education, positions held, availability and salary desired. Replies confidential.

P-8552, Control Engineering
520 N. Michigan Ave., Chicago 11, Ill.

Advertising In This Issue

Where specs are tight...



SPECIFY SUPERIOR BALL-BEARING POTENTIOMETERS BY

Designed for those applications where less than the best means failure . . . by the world's first and leading manufacturer of precision single-turn wire-wound potentiometers. Advanced production and quality-control techniques by the pioneer in mass production of precision potentiometers offer unequalled delivery . . . of prototype and production quantities.

All models of the TIC Ball-Bearing Series are designed to the latest industrial dimensions. Servo mounting is AIA standard. Stainless-steel ball-bearing construction is used for low-friction . . . low-torque operation. Other precision mechanical features include precious-metal slider contacts . . . centerless-ground stainless-steel shaft . . . and one-piece stainless-steel clamp ring developed by TIC for simple, precise phasing of individual units of ganged assemblies.

Designed for precision applications in automatic control systems, the subminiature ST09, for example, features standard independent linearity of $\pm 1\%$ (0.3%, special) of the total resistance, and $\pm 5\%$ standard total resistance accuracy. High resolution . . . equivalent noise resistance less than 140 ohms . . . wide standard temperature range ($-55°C$ to $80°C$) increases application versatility. ST09 is available in standard resistances of 100, 200, 500, 1K, 2K, 5K, 10K, and 20K.

Full specification on the ST09 and other units of the TIC precision ball-bearing series available upon request.

523 Main Street, Acton, Mass.
COlonial 3-7711
West Coast Mail Address
Box 3941, No. Hollywood, Calif.

TECHNOLOGY INSTRUMENT CORP.